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Enhancing the Stability of Anaerobic Vegetable Waste Digester through Sewage Sludge Supplementaion for Biogas Production – A Comparative Study.

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Abstract : Anaerobic co-digestion of vegetable waste and sewage sludge was studied extensively and the outcome of co-digestion was compared with the separate digestion of vegetable waste and sewage sludge. The continuous studies were conducted at an organic loading rate of 2 g volatile solids (VS)/l day and at hydraulic retention time (HRT) of 25 days. During the study period the vegetable waste reactor performance was severely affected due to low buffering and high production of volatile fatty acids (VFA) prevailed in the digester. Whereas sewage sludge digester incurred with low gas production due to acclimatization time required. From this study, it was observed that co-digestion of a mixture of vegetable waste and sewage sludge had shown a sizeable increase in cumulative gas production and specific gas yield (0.39 l and , 0.653 l per g of VS fed and drain respectively) compared to that of separate digestion of vegetable waste (0.25 l and 0.43 l per g of VS fed and drain respectively) and sewage sludge (0.34 l and 0.623 l per g of VS fed and drain respectively) while operating all three reactors at the same organic loading rate (OLR). The cumulative biogas production showed that the vegetable waste contains easily biodegradable organic matter compared with the sewage sludge and sewage sludge preferred buffering support for the vegetable waste digestion.
Keywords : Anaerobic digestion; Co-digestion; Vegetable waste; Sewage Sludge; Bio-Energy.

1. Introduction

Under Waste-to-Energy programme promoted by Ministry of New Renewable Energy Sources (MNRE) (Formerly Ministry of Non-Conventional Energy Sources), Govt. of India has demonstrated projects on Bio-Energy generation from Industrial and Municipal solid wastes at Koyambedu Market, Chennai, India[1]. It is Asia's biggest vegetable, fruit and flower market spread over an area of 60 acres with total waste generation 80 tones per day. To manage and treat those large quantities of vegetable wastes those are generated from the Koyambedu Vegetable Market, MNRE, Government of India proposed to implement a demonstration plant of capacity of 30 tones per day for market wastes for bio-energy generation and manure production under Waste-to-Energy programme at Koyambedu, Chennai. The Plant was constructed jointly with Chennai Metropolitan Development Authority (CMDA) and Central Leather Research institute (CLRI), Chennai as a technology institution and an implementing agency. Biomethanation projects usually have a number of other environmental benefits. For example, the anaerobic process destroys many pathogens that are usually present in human and animal waste and manure, while the slurry that remains is nutrient-rich and can be treated further and used as fertiliser. In general, biomethanation of urban waste reduces the amount of waste that would otherwise have ended up in open dumps[2].

It has been proposed that biomethanation of vegetable market waste along with sewage sludge to be experimented under Integrated Waste Management Schemes (IWMS) for continued and consistent bio-energy generation based on lessons learnt and hands-on experience gained from this project activity[3].Owing to the large biodegradable organic content of fruit and vegetable wastes (FVW), a major limitation of anaerobic digestion of these wastes is rapid acidification, which leads to higher Volatile Fatty Acid (VFA) production and subsequent accumulation in the reactor. The accumulation of VFA results in decrease in pH, which will affect the activity of *methanogenic* population when the feed stock is not adequately buffered[2]. Anaerobic digestion of FVWs without any co-substrate is a challenging task because their high simple sugars content often promotes fast acidification of the biomass with a resulting inhibition of methanogenic bacteria activity. To reduce the effect of acidification and bacteria inhibition processes, other substrates are often added for co-digestion. In fact, the addition of suitable substrates ensures a better process stability by keeping almost constant the volatile solids content and by avoiding the increase of easily degradable substances[5]. Citizens can be relieved from the nuisance of organic waste by scientific treatment through a cost-effective, quick, and non-polluting method or by recycling. Biological conversion of solid wastes containing higher percentage of organic matter by anaerobic treatment is the best possible option[6]. This process results in the recovery of useful energy in the form of biogas, thus reducing fossil fuel and green house gas sources[7]. Biofuels such as biodiesel, ethanol and biogas are getting more attention to address above issues[8]. The biogas is a renewable fuel that can be used as dual-fuel in the diesel engine without any modification to an engine [9, 10]. In addition to being available easily, renewable and cheap, biogas can make a good substitute for diesel fuel. Emission of carbon monoxide, oxides of nitrogen and smoke are decreased[11].

Co-digestion is a technology that is increasingly being applied for simultaneous treatment of several solid and liquid organic wastes[12, 13]. It combines different organic substrates to generate a homogeneous mixture as input to the anaerobic reactor in order to increase process performance. The prominent features of co-digestion include: dilution of potential toxic compounds, improved balance of nutrients, synergistic effects microorganisms, increased load of biodegradable organic matter and better biogas yield[14]. Sewage sludge (SS) is being generated in enormous quantities from sewage treatment plant, Koyambedu, which is treating sewage of about 60 million litres per day (MLD). Recent restrictions on the use of sewage sludge, however, have resulted in increased disposal problems[15]. SS has a high C: N ratio varying from 6:1 to 16:1. The addition of SS to VW digestion process provides the nitrogen as well as other nutrients that are not present at sufficient levels in vegetable waste.

The overall purpose of this study was to assess the technical feasibility of co-digestion process of VW and SS to execute with the Koyambedu vegetable market waste anaerobic digestion plant for enhanced biogas production. The assessment was done by comparing the effect of co-digestion of VW and SS on reactor stability and biogas production with the separate digestion of VW and SS. In this present study, the relationship between the process control parameters pH: Volatile Fatty Acids (VFA): Alkalinity[16], which has direct effect on biogas production, was extensively studied.

2. Experimental

2.1 Reactor set-up and process description

A laboratory scale reactor of total volume of 2 liters made up with borosilicate glass was used for this study (Fig.1). The effective volume of the reactor was 1.5 liters and it contained two openings. One was used for feeding and another for releasing of the gas produced. The openings were closed with the rubber cork so that the air could not enter the reactor and the biogas produced cannot escape outside but into the aspirator. The reactor was connected with the aspirator, which is also made up with borosilicate glass and 2 liter capacity, through flexible rubber tube.

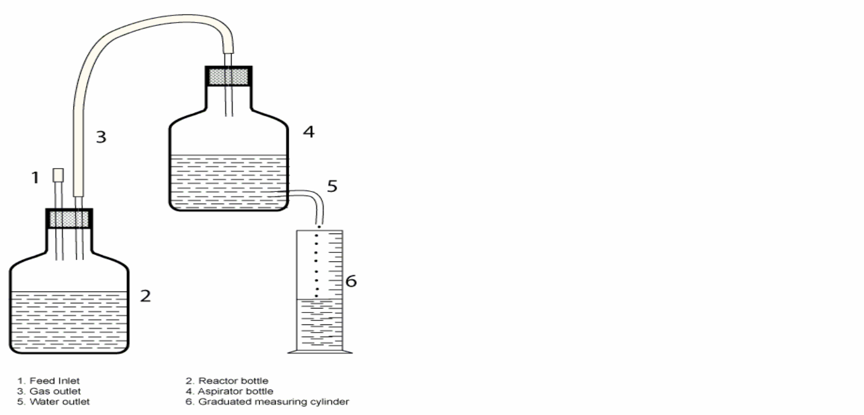

Figure 1.Reactor set up.

The produced biogas collected in the aspirator, which is filled with acidified water. The aspirator was set up in a way that would expel the water equivalent to the gas entered. Hence, the amount of gas produced is equivalent to the displaced water content[17]. The reactors were operated by draw and fill method. The required amount of digested material was withdrawn from the reactor before feeding. Three reactors were used in this study. (Table.1) The experiment was carried out under mesophilic conditions (25 ± 5ºC).

Table1. Process description

Reactor	Substrate
I	Vegetable waste
II	Sewage sludge
III	A mixture of 75% by VS) Vegetable waste and 25 %(by VS) Sewage sludge.

2.2. Inoculum and feedstock preparation

The reactor was initially fed with predigested cow dung which is rich in anaerobic microorganisms was used as inoculum. Samples were collected from the vegetable market, and taken into the laboratory for characterization. All wastes were macerated using a domestic food blender so that, the wastes had been reduced to the smallest possible sizes. Then the wastes were stored in a refrigerator at 4°C until use. Before use, the original total solids concentration (TS %) and volatile solids concentration (VS %) of the waste was determined.

The SS obtained from sewage treatment plant was stored at 4°C in refrigerator for less than two weeks prior to use as feed. This sludge was also screened with 1 mm sieve to remove impurities and to prevent the clogging problems during the transfer from the feed tank to the digesters.

2.3. Process description

Preliminary experiments were carried out with different combinations of VW and SS (Data not shown). From those experiments it was found that the mixture of VW (75% VS) and SS (25% VS) divulged hopeful give up combination. The reactors were fed and drained once a day (operated in quasi-continuous mode) [18]. Feeding was conducted for 6 days a week. Reactors were stirred daily by shaking and swirling once every day before drain and feeding of the reactor. All three reactors were operated at on organic loading rate (OLR) and hydraulic retention time (HRT) of 2 g VS/l day and 25 days respectively.

2.4. Analytical methods

The feedstocks were analyzed for pH, TS% and VS% before being fed to the reactor, whereas the drained samples were analyzed for pH, Temperature, TS%, VS%, VFA and TA. All analysis was carried out according to the APHA standard methods[19]. Total biogas yield and gas composition (CH_4 and CO_2) were measured on a daily basis using the water displacement method. Gas samples were collected by gas sampling and its composition was determined using ORSAT apparatus.

3. Results and Discussion

3.1 Analysis of substrate and feedstock

In order to understand the fundamental physiochemical characteristics of the organic wastes to be treated, i.e. VW and SS were analyzed thoroughly before being fed to the reactor (Table 2). It is apparent from the values of VS and VFA the wastes available from vegetable market containing easily biodegradable organic matter and sewage sludge due to its high alkalinity and low VFA value are of demanding interest for their anaerobic co-digestion[20].

Table 2. Properties of feedstock

Parameter	VW	SS	VWSS
pH	4.17	7.26	5.45
Temperature (°C)	32	33	31
Total Solids (%)	5.76	8.14	6.65
Volatile Solids (% of TS)	87.14	62.92	80.70
Volatile Fatty acids (mg / l)	4781	3800	4750
Alkalinity (mg / l)	750	8000	2333

3.2 Anaerobic digestion of vegetable waste

In vegetable waste reactor a gradual decrease in pH from 6.78 during day 1 to 5.4 during day 5 was observed (Fig. 2). The drastic decrease in pH is due to two reasons; low pH in the feed stock (4.1 – 4.5) and steep rise and fall in the VFA and bicarbonate alkalinity levels respectively. The feedstock was supplemented with $NaHCO_3$ to raise the pH. Addition of $NaHCO_3$ reflected in the reactor pH, which was stable between 6.4 and 6.7[21]. The TS (%) was reduced from the range of 5.5 ± 0.5 to 2.6 ± 2 after anaerobic digestion. Whereas VS (%) in the feed and drain samples were in the range of 83 – 90 to 55 - 70 respectively. TS destruction is a vital aspect in evaluating anaerobic digestion performance[22].

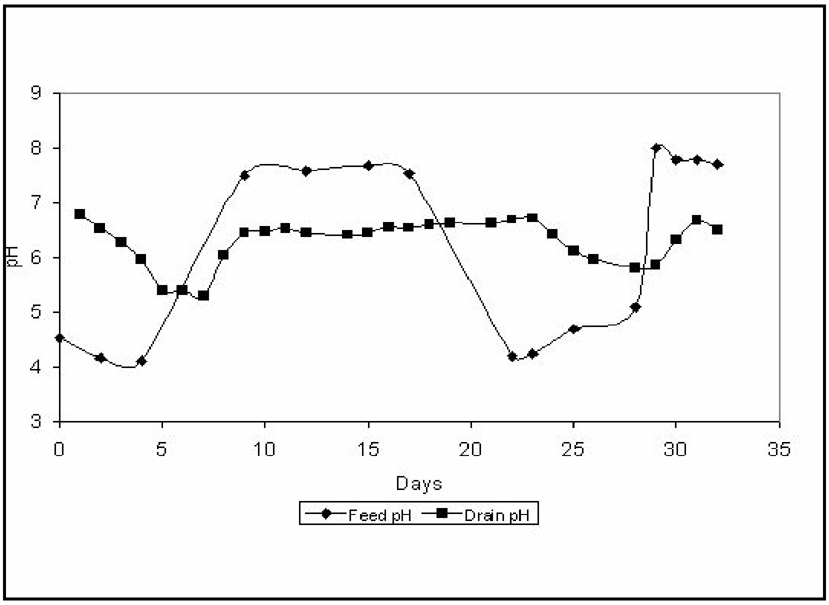

Figure 2. Variation of pH with time for vegetable waste reactor.

The concentration of VFA has been found to be a good indicator of the metabolic status of an anaerobic degradation process. The VFA and TA with respect to time are shown in Fig. 3. There was a gradual increase in VFA and alkalinity values up to 14,000 mg/l and 15,000 mg/l respectively in the whole operation period of 32 days. In a well balanced anaerobic digestion process, total VFAs levels ought to be low. In anaerobic digestion even small accumulations of VFA in the reactors results in the consumption of bicarbonate and a decrease in pH results if buffering capacity is not adequate. Failure of anaerobic reactor appears to have been due to inadequate levels of alkalinity to balance the levels of VFA in the digestion liquors. The major criterion for judging the digester stability is VFA: alkalinity ratio[23]. For stable digestion, it is imperative that a satisfactory ratio be maintained between VFA and alkalinity levels.

Anaerobic digestion of vegetable waste is inhibited significantly to the buildup of VFA at a higher loading as well as owing to the fact that increasing the density of the solid waste tends to decrease the gas production. Thus it is imperative that the OLR and HRT are kept optimal and also proper buffering is maintained. The present investigation suggests that the OLR of 2 and 25 days HRT are not optimal, anyone of the two parameters should be changed.

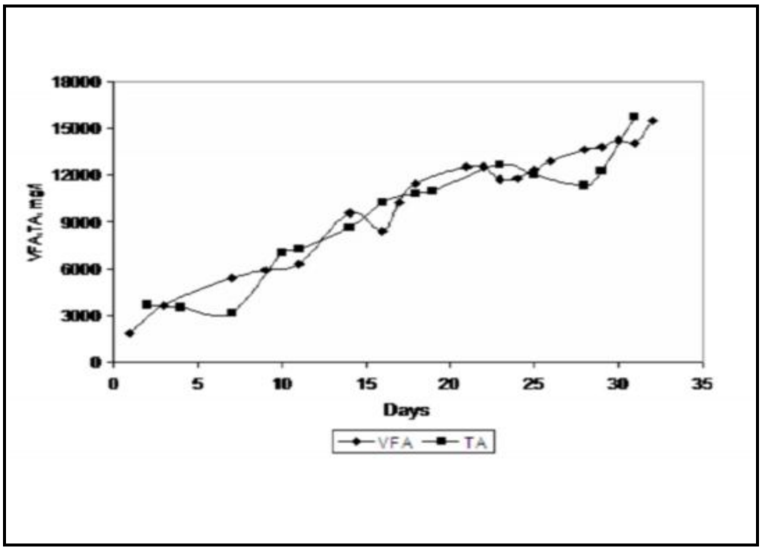

Figure 3. VFA (mg/l) and TA (mg/l) with time for vegetable waste reactor.

Metabolic relationship and the substrate and product's effect on the route of metabolism are indicated by the gas production in the anaerobic digestion. The variation of daily gas production with VFA exposed in (Fig.4) is substantiation of the above mechanism. The graph clearly shows the influence accumulation of VFA in the gas production. The initial high gas production shows that the degradation of substrates immediately. The gradual decrease in gas production from 1300 ml to 500 ml is due to the decrease in pH, VFA accumulation and inadequate levels of TA[24]. From the gas production profile it was observed that on certain days of experimentation, descend in the average daily gas production. However, on successive days a net rise in overall gas production was registered. It was owed to the fact that the reactor was not loaded during the weekends, causing a net decrease in the gas production. Because of reloading the reactor, there was a gradual increase in gas production on successive days. Similar kind of tendency was observed earlier[25].

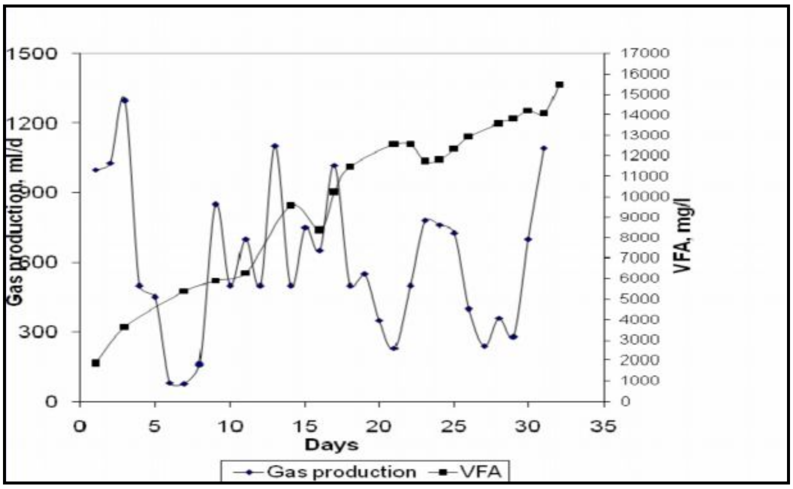

Figure 4. Gas production (ml/d) profile with VFA (mg/l) for vegetable waste reactor.

Though addition of $NaHCO_3$ solution increased the pH of slurry to 7.3 it could not revive the gas production in the reactor significantly. The specific gas production per g of VS fed and drain were 0.25 l and 0.43 l respectively. The results are comparatively less with the average specific gas yield 0.5 - 0.6 l/g VS $_{fed}$, 0.58 l/g VS $_{fed}$ [26] and 0.403 l/ g VS fed[27]. It was observed that higher loading rates abridged the specific methane yield, energy conversion efficiency and led to drop in digester pH which could not be effectively controlled by alkali additions, it was also stated that to maintain digester stability it was necessary to supplement with additional trace elements or co-substrates[28].

3.3 Anaerobic digestion of sewage sludge

The digested material pH was in the range of 6.8 -7.5 which is optimum for methanogenic conversion of VFA (Fig.5). The TS (%) was reduced from the range of 8.25 ± 2 to 2.4±3 after anaerobic digestion. Whereas VS (%) in the feed and drain samples were in the range of 57±1 to 54±1 respectively.

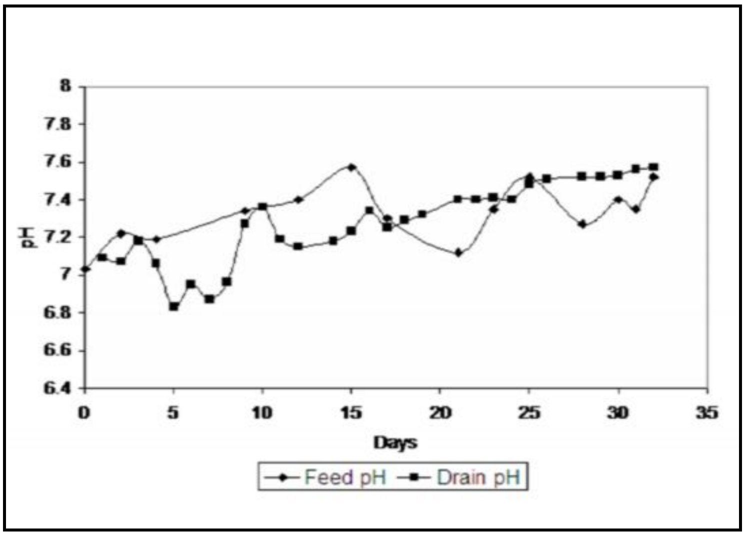

Figure 5. Variation of pH with time for sewage sludge reactor.

However, due to large variations in feed sludge characteristics steady digester operation was not possible using a constant feed volume. Therefore the VS loadings were maintained constant by daily adjustment of the feed sludge to water ratio. It has been observed from figure 6 that a gradual variation of VFA from 1125 mg/l to 7250 mg/l and in TA from 2830 mg/ml -to 8500 mg/ml. Unlike the vegetable waste reactor, the organisms needed an acclimatization time with the sewage sludge substrate, which is evident from the VFA and TA profile with time (Fig.6). The adaptation time required was 10 days, as there was no build up in the

VFA level during this time. After 10 days, there was gradual increase in the VFA level. This is evocative of the fact that SS studied had widely varying chemical constituents in comparison with VW. This contradicts the concept of VW and SS are similar in character. However, an estimation of the individual constituents of the two wastes is necessary to ascertain the similarities of the wastes. The drop in VFA level during days 18 – 30 was perhaps due to its rapid uptake and subsequent gas formation.

The daily gas production (ml) was increased gradually for the operation period of 35 days from 150 to 1650. There was a considerable variation in the gas production and the influence of VFA concentration reflected directly on the gas production with respect to time (Fig. 7). Thus VFA – gas production relationship was a good indication of stabilization of anaerobic digestion of sewage sludge. The specific gas production per gram of VS fed and drain were 0.34 l and 0.63 l respectively.

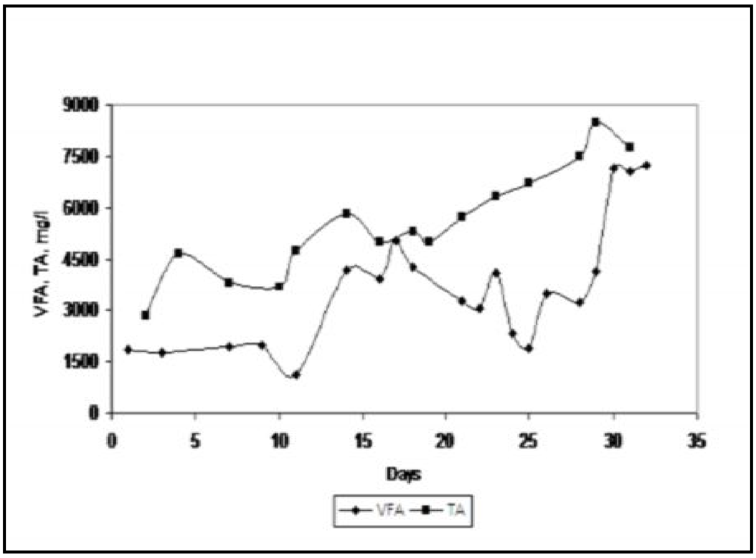

Figure 6. VFA (mg/l) and TA (mg/l) with time for sewage sludge reactor.

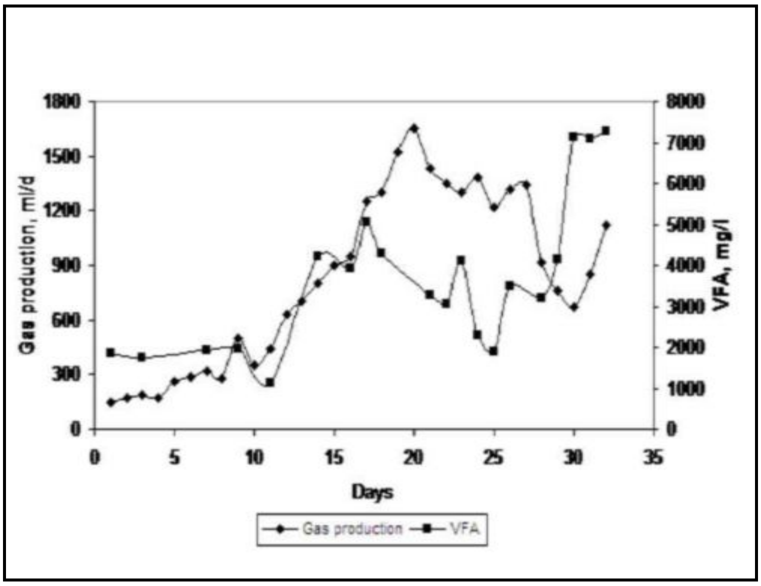

Figure 7. Gas production (ml/d) profile with VFA(mg/l) for vegetable waste reactor.

3.4. Co-digestion of Vegetable Waste and Sewage Sludge

In this reactor the pH of the digested material was within the range of 5.9 - 7.5. Similar to vegetable waste reactor, a decrease in pH was observed after 4 – 5 days. Following the increase in feedstock pH to 7.3 ± 0.1 by the addition of $NaHCO3^-$ (Fig. 8), the feat of the reactor was improved. After a week, the addition of the

$NaHCO_3^-$ was stopped. But unlike the vegetable waste reactor, pH did not decrease thereafter. The pH was stable at around 7.3 - 7.5, which was due to the fact that SS provided enough alkalinity for buffering organic acids produced during the process and also stabilized the reactor.

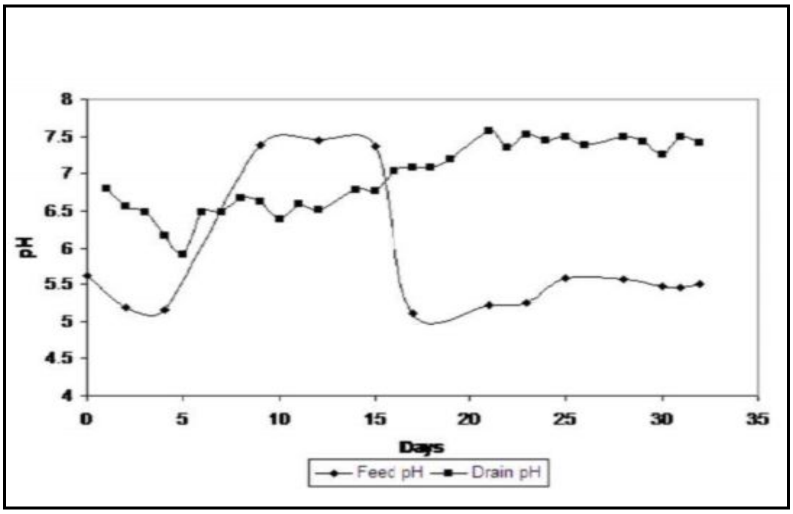

Figure 8. Variation of pH with time for co-digestion of vegetable waste and sewage sludge reactor.

The TS (%) was reduced from the range of 6.2 ±0.5 to 2.5±1 after anaerobic digestion. Whereas VS (%) in the feed and drain samples were in the range of 78±3 to 62±10 respectively. It is prone that high degradation efficiency in the co-fermentation was due to an improved ratio of nutrients and better availability of the organic substances, which facilitate their assimilation by anaerobic flora and increases the degree of degradation. The proportion of SS added to the mixture was 25% (by VS). It was reported that SS could act as a substrate for anaerobic digestion and also a bacterial inoculums [25].

Though there was a gradual increase in VFA and TA, it has been observed that after 15 days the VFA and TA ratio was maintained in such a way to enhance the anaerobic digestion (Fig.9). This could accomplish due to the fact that, the feedstock contained a major fraction of VW (75% by VS) and less SS (25% by VS), so it is easily biodegradable and produced more VFA which led to its accumulation in the system.

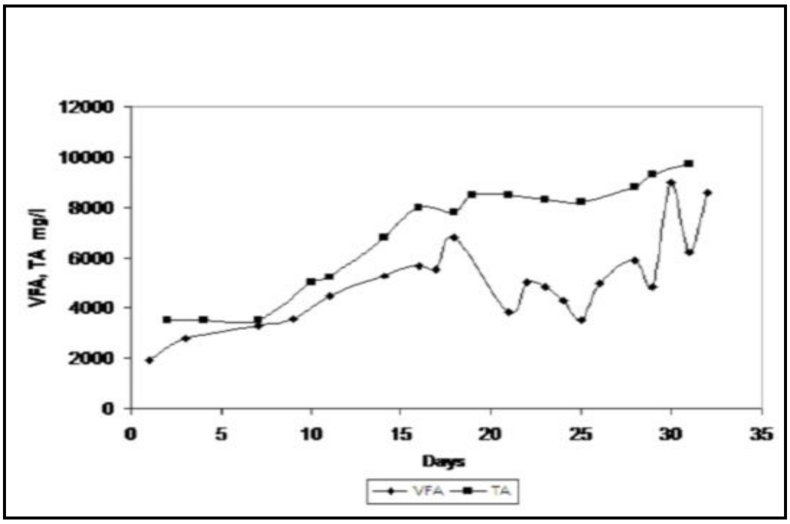

Figure 9. VFA (mg/l) and TA (mg/l) with time for co-digestion of vegetable waste and sewage sludge reactor

One of the limitations of the reactors performance might be hydraulic overload causing a washout of the micro - organisms. Another cause could be organic overload, where the inhibition of the microorganisms was happened by the accumulation of VFA. Owing to the low buffering capacity, the digester liquid pH decreased which led to further inhibition. After a week, there was an increase in digester pH, VFA and TA ratio and also the gas production. It might be, owing to the fact that SS was started to degrade and provided enough alkalinity for buffering of organic acids produced by theVW (Fig. 10).

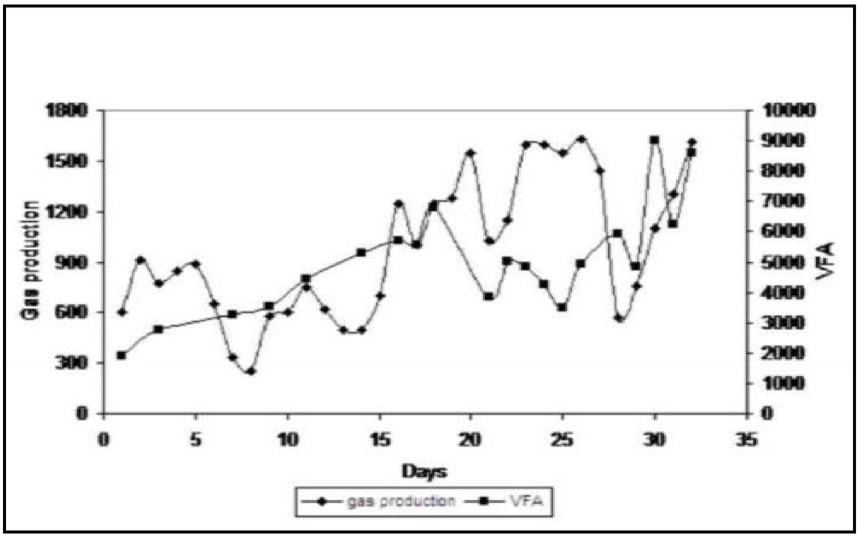

Figure10. Gas production (ml/d) profile with VFA(mg/l) for co-digestion of vegetable waste and sewage sludge reactor.

Consequently, the occurrence of an imbalance among the different groups of anaerobic bacteria which may take place in an unstable anaerobic digestion of VW process could be prevented[25, 29]. The specific gas yield 0.71 l/g VS_{des} was seems to be reasonably high with the specific gas yields like 0.544 l /g VS_{des}[29], and 0.6 l/g VS_{des}[30].

The SGP/g /g VS_{in} , SGP/ g VS $_{des}$, total biogas yield etc. were used as the parameter for evaluating the performance of the anaerobic digestion system [31]. The cumulative gas production for VW, SS and a mixture of VW and SS reactors were measured as 18.635 l, 26.480 l and 31.17 l respectively. Comparison of the specific gas yield per g of VS fed and drain values of VW (0.25 l& 0.43 l), SS (0.34 l & 0.66 l), and co-digestion of VW and SS (0.42 l & 0.71 l) again validates the advantage of co-digestion (Table 6). The increased gas production in the co-digestion process was due to better nutrients balance in the feedstock, constructive synergism and the correct activity of microorganism in the digestion medium. The ratio of methane to carbon dioxide determined by ORSAT gas analyzer was in the range of 50:40–51:45. The efficiency of these three reactors could clearly be exposed from this study, where the co-digestion evidently outsmarts the other two.

Table 6 - Performance analysis of reactors

Particulars	**Vegetable Waste Reactor**	**Sewage Sludge Reactor**	**Vegetable waste and Sewage Sludge**
Total Volatile Solids in feed, g	73.98	77.25	74.75
Total Volatile Solids in Drain, g	30.98	37.29	30.91
Volatile Solids Destruction, g	43	39.96	43.84
Destruction Efficiency, %	58	48.27	58.64
Total Gas Production, l	18.65	26.48	31.17
Specific Gas Production, l/g VS_{in} (SGP/g /g VS_{in})	0.25	0.34	0.42
Specific Gas Production, l/g VS $_{des}$(SGP/ g VS $_{des}$)	0.43	0.66	0.71

The gas yield obtained for the co-digestion of VW and SS may be compared with previous works. Continuous co-digestion of cattle slurry with fruit and vegetable wastes and chicken manure was examined and reported gas yield of 0.37 l l/g VS added[23]. All the above cited proved the consistency of our results and strongly supported that the operating parameters such as OLR, HRT and process control parameters like pH, VFA/Alkalinity should be continuously monitored and maintained to improve the process stability and efficiency of the anaerobic reactors.

4. Conclusion

Anaerobic systems for VW are susceptible to frequent disruptions at high loading. Improper buffering is observed to be the main reason for system failure. Proper balance between pH – VFA – TA is of at most importance in large-scale operation of anaerobic system. SS can also be degraded anaerobically, provided the sludge is acclimatized to the reactor environment. The need for acclimatization of SS proves that VW and SS vary widely in their composition, which is contrary to popular belief. However, sludge composition is site-specific and should be analyzed for each case. Better performance of the digestion system was observed for the co-digestion substrate. Co-digestion benefits include improved balance of nutrients, synergistic effect of microorganisms, increased load of biodegradable organic matter and better biogas yield. Complete composition profile of VW and SS needs are customary to clearly understand the anaerobic reaction pathways. The present investigation strongly favors that co-digestion of vegetable waste and sewage sludge seems to be an attractive method for waste management, environmental protection and energy savings.

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