International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I5P216
Volume 69 Issue 5, 109-118, May 2021

Effects of Process Variables on Biomethane Productivity in Anaerobic Digestion of Market waste co-fermented with Food Waste

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Abstract –

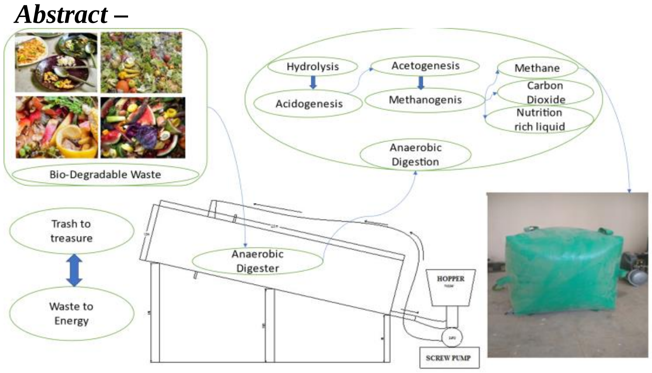

Fig 1. Schematic representation of Anaerobic digestion

The Factors which have a high impact on the production of biomethane from dry, continuous anaerobic digestion of the organic fractions of the market waste containing fruit and vegetable mixture (FVM) co-digested with food waste (FW) are examined. The effects of functional variables such as organic loading rate, hydraulic retention time, C/N ratio, temperature, alkalinity and pH, volatile solid reduction on biomethane productivity were studied in an anaerobic digester with a single stage of plug flow type. In the AD of organic fractions market wastes, substrate-induced volatilities of fruit and vegetable waste (FVW) lead to poor production of biogas. Hence FVW mixture ratio is fixed at 2.2:2.8 for optimum yield and then it is co-fermented with food waste and previous digestate with a 2:1:1 inoculum ratio and results have been investigated. And the AD is operated for a fixed Hydraulic Retention Time (HRT) of 25 days and the optimal organic loading rate ranged between 2.5 to 12 kg VS/m^3*.d with the moisture content of 76.4 to 82.25 %, Total solid (TS) concentrations of 17.75 to 23.6 %. It is noted, from the results, that the best performance of AD, achieved at OLR 7.5 kg VS/*m^3*.day with 67 % reduction in Volatile Solid and 0.576* m^3 *of biogas produced per kg* $VS_{removed}$ *in loading* L_3*.*

Keywords — *Anaerobic Digestion, Market waste, organic loading rate, Total solid pH, Volatile Solid reduction, thermophilic conditions.* [1]

I. INTRODUCTION

Anaerobic Digestion (AD) is a process in which a group of bacteria and anaerobe archaea reduce and stabilize organic waste of different kinds in an oxygen-deprived environment, thus producing energy-rich biogas. Biogas contains primarily CH_4 and CO_2 used as a source of heat and electricity, energy, and also as fuels in automobiles [1], [2], [3] [4]. It can thus be summed up that, the AD technology contributes energy, pollution-free environment, waste reduction, and other positive attributes in terms of environmental sustainability to society. Although the process offers various benefits, it has certain constraints like the stability of organic waste, volatile solid loss rates, which are primarily responsible for variations in the rate of biogas output, and substrate-influenced process instabilities [5], [6].

[1] This research work supported by grants from the Ministry of Science and Technology, Govt. of India under (Project No.: SB/EMEQ-337/2014) by Science and Engineering Research Board, Department of Science and technology.

The Process productivity and biogas yield are closely related to the substrates, operating conditions, and partly the kind of digestive techniques adopted [7], [8]. The volatile fatty acid (VFA) accumulation and ammonia in excess will adversely affect the stability of AD, the deposition of VFA prevents methanogenic activity by acidifying the AD process [9] [10], [11], [4]. AD of Fruit vegetable waste (FVW) as the base substratum, is difficult because VFA aggregation appears to be caused by highly soluble degradation of the basic sugar [12]. Many reports have shown AD instabilities due to the digestion of FVWs as a single substratum [13], [14] [15]. The use of alkaline chemicals as a pH modifier for a range of 6.8 to 7.2 is a standard method for the control of acidification. Therefore, the acidifying process is to be neutralized. The buffering ability of AD increases when the co-digestion of various substrates in the digester [16], [17], [18] [19], and which enhances the microbial activity supports AD [20]. In contrast to mono-digestion, [6] recorded an improvement in the yield and the consistency in processes during food waste digestion with FVWs at 1:3. [20] found that the yield of CH_4 increased in co-digestion by 5% of FVW's by 22.4%. Co-digestion may increase the CH_4 rates by 18-48%, as noted by [21].

In addition to co-digestion, handling Total solid (TS) concentrations have improved the efficiency of the digester operated with FVW. A substrate with a TS concentration of less than 6% promotes process solidity, with the reduced biogas output as recorded [14]. [13] have noted high volatile solid degradation (HV) in FVW digester with a 5% TS concentration. [9] identified an equivalent, FVW mixture as a feedstock can ensure an efficient acidification control, often resulting in process instability. Vegetables are a source of proteins, vitamins, minerals, dietary fibers, and micronutrients in our everyday diet. The wide-range variety of soil and climate made diversified plants grow in the tropical, subtropical, and temperate regions of the nation. Over 40 types of vegetables belonging to various groups are grown across. There is plenty of food waste every day in the food markets and waste disposal is a severe problem. The current methods of disposal of vegetable waste, municipal waste, dumping landfills and livestock feeding are non-scientific practices that contribute to contamination of the environment, such as soil, water, and air [22]. The biological treatment of vegetable waste is economical and also reduces environmental pollution [23]. In the various biological methods, Biomethanation is an appealing choice because it produces energy-rich biogas [24], [25] with nutritional value for effluent from the Biomethanation plant [26].

Many studies on AD of vegetable waste were recorded for biomethane potential, among them [27] conducted biogas production from vegetable waste, at The various concentrations of organic loading (OLR) are 1.4, 2, and 2.75 kg VS/m^3.d. The yield of biogas from 0.12 to 0.4 m^3 of biogas per kg VS input at OLR of 1.4 kg VS/m^3.d and CH_4 content ranging 49.7 to 64 % with an average methane yield is 0.25 m^3CH_4/kg.VS, 88 % VS loss. [28] conducted AD of the vegetable waste mixture in a 2L mesophilic single-phase anaerobic reactor. The reactors were run in two separate OLR's 0.25 and 0.5gVS/L.d with 25days of HRT. Biogas yield at two OLR rates was an average of 0.150 and 0.300L / day, and the percentage of conversion for TS and VS was between 53-62% and 62-67% with TS 0.393 and 0.522 l/g and VS 0.43 and 0.576 l / g. The CH_4 content of the gas was about 63%, while the gas yield of both OLR's was 0.226 and 0.362l CH_4/g.VS input [28].

In a laboratory-scale digester capacity of 10L batch of mixed vegetable market waste [22] used 5% Total Solid (TS), after 41 days, biogas yield was observed at 0,15 m3 / kg TS. It was observed at a maximum rate of 650 ml/h on day 25 of biogas generation, and a decrease of about 65% was seen in Chemical Oxygen Demand (COD). Several researchers studied the Biomethanation of vegetable waste in scale-up experiments, [29] researched anaerobic organic waste digestion at OLR 0.8 kg VS/m3.d, the biogas yield 0.26 m^3/kg.VS with 60% CH_4 and 61% of Volatile solid loss attained. [30] developed a mathematical model that is deterministic to satisfactorily predict the features of an AD.

The analysis was performed under the Hydrolytic Reactor (HR) - and Mesophilic Reactor (350C) (MR), conditions MR & HR at 4 and 20 days, OLR at HR, and MR at 10 g VS L, 5 g VS L^{-1}. With 60 ± 3 % methane. The biogas yield was approximately 660/g.VS methane. Solid plant waste Biomethanation with a two-step digester was studied: 100 liters of hydrolysis and acidification of the solid bed digester and 24.6 L of biogas processing reactor of anaerobic sloud blanket (UASB) up flow. A 94 percent decrease in COD was achieved during UASB organic loading operations of 19, 6 kg of COD day 3[31].

Vegetable waste has a high level of carbohydrates and moisture therefore, it's a suitable source for biogas production. Many scientists have researched the production of biogas from a mixture of vegetable waste. The biogas production ranged from 0.360 L/g VS to 0.9 L/g VS. Temperature, pH and organic loading, COD and alkalinity are operating parameters that have a direct impact on vegetable waste Biomethanation, the reactors of different designs often monitor production rate. The catalysts usage in the anaerobic digestion enhances biogas yield. Biomethanation also reduces the burden of TS, VS, BOD, and COD pollution by organic pollutants. Biomethanation, therefore, tends to be a renewable technique for waste management. Some experiments with FVW and FW were performed to enhance anaerobic digestion in combination with other organic waste at mesophilic temperatures. However, there is little understanding of FVW's and FW's digestion under thermophilic conditions.

The current assertion that digester instability can be adequately examined by VFA/TA and pH is further supported by this study, whereas OLR is an effective control technique. In the light of this anaerobic digestion of FVW and FW co-digestion, high biogas efficiency and operative stability are thoroughly analyzed. A pilot anaerobic digester is currently being studied for the effect of dry and continuous anaerobic fermentation of the market waste co-digested with food waste on the factors affecting biomethane productivity. The functional variables including OLR, pH, VFA, Temperature, Alkalinity, and pH were measured; also volatile solid loss was recorded for a fixed HRT of 25 days. The entire experiment took 100 days and the optimal working conditions were tested.

II. METHODOLOGY

A. Characteristics of organic fractions of Market Waste and inoculum

Market waste from APMC Market, Chikkaballapura, and VIAT canteen food waste are used as substrates for an AD. The processing of biodegradable waste, which contains a mixture of cooked food, fruit, and vegetable waste. These are collected in a container after manual sorting and then it is crushed with a shredder to an average size of 6 mm, smaller size increases the surface area and the hydrolysis process, which is a limiting aspect in anaerobic digestion for the production of methane. Based on BMP measurements, the organic ratios of the market waste containing fruit and vegetable mixture (FVM) is set at 2.2:2.8 and co-digested with food waste (FW) and previous digestate. A key element in determining waste-to-inoculum ratios and anaerobic biodegradability estimates of solid waste is the source of the inoculum. The components of inoculum cow dung, digestate matter, and FW were combined in a 2:1:1 ratio to activate the anaerobic digestion mechanism and acclimate the reactor. This balanced ratio has been used to optimize microbial diversity within the reactor [33] to improve the C/N ratio [32][12]. Table.1 illustrates the characteristics of organic fractions of the Market Waste and Inoculum, including the contents of moisture (MC), the total solid (TS), volatile solids (VS), the total demand for chemical oxygen (TCOD), and the ratios of carbon-nitrogen for FV, FVM, and inoculum. The study lasted for 100 days with 100 kg to 250 kg of FVWs from the nearby APMC Market, Chikkaballapura, and showed a stable process.

TABLE-I
CHARACTERISTICS OF ORGANIC FRACTIONS OF MARKET WASTE, FW, FVM, AND INOCULUM.

Parameters	pH	Moisture content (MC) %	Total solids (TS) %	Volatile solids (VS) %	TCOD mg/kg	C/N ratio
Food Waste	5.34	77.7	22.3	19.98	220350	22
Fruit & Vegetable waste Mixture	6.39	90.23	9.23	6.18	270000	45
Inoculum	7.8	80.07	19.53	11.5	71850	29.3

B. Experimental design and preparation of feedstock

To maximize biogas generation and to determine operational parameters for the designed organic loading rates and hydro-control period, a single-stage Plug-Flow anaerobic digester (PFD) was used at various organic load rates. The tank is made of stainless steel sheets that are 1000 mm diameter and 2,000 mm long, as shown in Figure 2. (a) [34]. The inner tank made concentric with a mild steel outer cover and a 20 mm thick rock wool, was reinforced for thermal insulation to decrease heat transfer to the atmosphere. A steel tube has been helically fixed to the inner side of the digester to keep the PFD temperature under thermophilic conditions. A hollow, stainless steel tube is often mounted and attached to a bearing, which is an edge-conscious agitator, to maintain the temperature at the center, to ensure that the digestate is properly mixed as shown in Fig. 2. (a) Assembled PFD system (b) the inner view of digester [34].

Additional accessories, like a geyser to enable convective heat transfer via circulation of hot water, are provided with the plug-flow digester to maintain thermophilic conditions and a flow meter to measure biogas. An inlet pipe is connected to the top of the tank by a progressive pump connected to a 300-liter hopper at a height of 1700 mm from the base to load its supplies. The second is attached to the $7m^3$ biogas storage balloon and two outlets are installed at the bottom for the removal of digestate without air intrusion. At a 38° inclination, the whole digester is installed on a mild rigid steel stand to ensure easy loading and disposal of the feedstock. A progressive screw pump, a geyser, a pressure booster pump, and a compressor are used for circulating the food waste, water, and gas produced [34] through PVC pipes.

(a)

(b)

Fig. 2. (a). Assembled picture of the PFD system (b) Inside view of the digester[34]**.**

As per previous studies, the initial load with 600kg cow dung and 300kg fresh FVM was made to 3/4 of the actual digester ability with a 2:1:1 inoculum ratio [35]. The Charge is homogenized before feeding into the system [36], [37], [38]. The temperature increased gradually to the thermophilic range (55°C) at a step of 5°C [34], [39]. Once the methanogenic process achieves stabilization, daily and cumulative biogas outputs are measured for 25 days of hydraulic retention and various loading conditions. The compositions were eventually studied. Results show that lesser the pH value (below 6.0), implies that volatile fatty acids are accumulated, and thus prevents methanogenic activity. In the initial phase, carbon dioxide is high, due to trapped air in the PFD, and the methane concentration was almost negligible during that time. The ammonium concentration in an anaerobic digester at levels up to 1000 mg / L is a critical limiting factor for the buffer ability. The caustic soda (NaOH) has been added when the pH of the system declines below 6.0 [23], to maintain the pH value. When digestate was regulated with the pH range of 6.8 to 7.4[40], anaerobic digestion recorded the maximum methane.

The PFD is operated at different rates of organic loading (OLRs) before optimal conditions are reached. OLR increased gradually, from 2.5to 12 kg VS/m3.day and the moisture content of 76.4 to 82.25 %, Total solid (TS) concentrations of 17.75 to 23.6 % with fixed HRT of 25days. Table.2 summarizes the AD process strategies and functional parameters. Diversified volumes of FVWM digested with FV for each load has been added to the digester once a day for the complete duration of the test to check the effects of the operational parameters such as OLRs, pH, TS, VS loss, Temperature, Alkalinity on the efficiency of PFD, besides, continuous AD monitoring is necessary at each OLR to increase to achieve stable results till the desired load.

TABLE-II
METHODOLOGIES AND FUNCTIONAL VARIABLES OF ANAEROBIC FERMENTATION.

Loading	Hydraulic Retention Time (HRT)	Organic Loading Rate (OLR) kg.VS/m3day	Total solid %	Volatile solid %
L_1	25	2.5	18.8	84.08
L_2	25	5	17.75	77.45
L_3	25	7.5	21.75	83.23
L_4	25	12	23.6	79.2

C. Organic waste features and estimation Biogas constituents

Fresh inoculum, effluent, and biogas from PFD have been collected and evaluated daily during each process to enhance its efficiency. The Standard measurement methods used for measuring TS, VS, and pH are characterized in the Digestate samples (Apha, 2005). A wet gas meter measures the daily biogas generated (Elster BK G 1.6, India), and its Composition (CH 4, CO2, H2S &O2) Recorded by the biogas analyzer (IRCD4, Beijing shi'an science instrument co., Ltd, China), collected in the Tedlar bar sample sachets. The Biogas quantities are yielded based on many functionalities, including hydraulic retention time (HRT), temperature, trace metal, C/N ratio, organic loading rate, partial pressure, pH levels, substratum composition, anaerobic microbes, and oxygen exposure.

III. RESULTS AND DISCUSSION

A. Effect of pH on the Daily Biogas Production

The pH is an important process parameter for the management of the biogas processes and it is sensitive to atmospheric conditions. The process may or may not be stable depending on the pH of liquid leachate from the digesters. Its variation depends on the buffering capacity of the AD. The daily biogas production and pH variations are shown in Fig 3. (a, b, c, d), During the stable operation stage, the mean daily biogas productions were 1274.028 L/day with mean pH being 7.83 for loading L_1 it's observed from the pH variation curve from Fig.3(a) that there are no much fluctuations in pH as digester already reached steady state since the quantity of fresh feedstock was less.

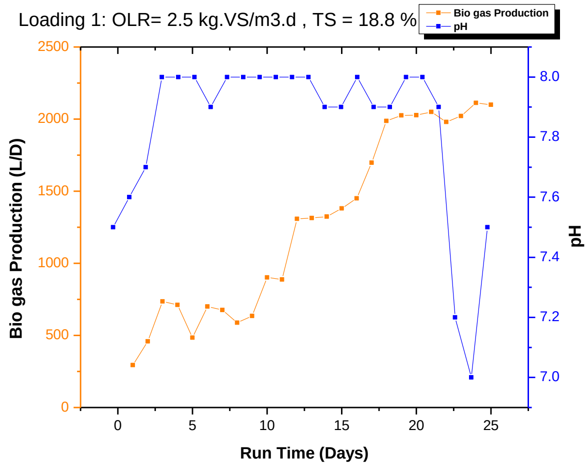

Fig. 3(a).

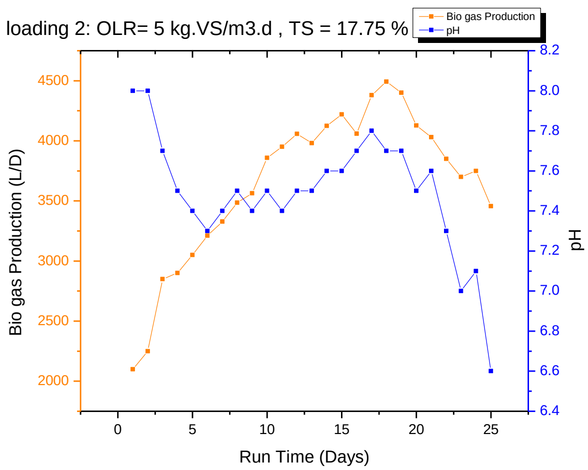

Fig. 3(b).

In loading L_2 there were slight fluctuations in the pH values even then it doesn't affect the digester performance since it was in the methanogenic range i.e. from 6.6 to 8.0 and the mean biogas production 3647.12 L/day with mean pH 7.5 as shown in Fig.3(b).

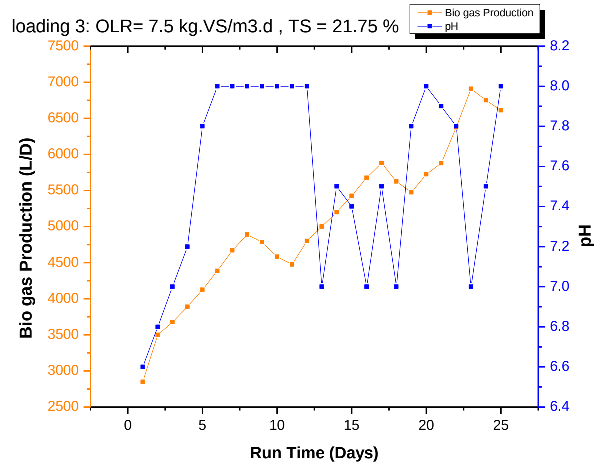

Fig. 3(c).

In loading L_3 the pH values were stable till the 14th day soon after that it was fluctuating as the accumulations of Volatile fatty acids started due to increased OLR and Total solid content. The maximum specific biogas 0.57583 m3 produced per Kg of volatile solids removed. The mean biogas production was 5086.2 L/day with mean pH 7.552 Fig.3(c). Furthermore, an increase in OLR and Total solid content leads to a decrease in the productivity of the Anaerobic digester i.e., reduction in biogas production 7627.64 L/day with pH 6.95 for loading L_4 as shown in Fig.3(d).

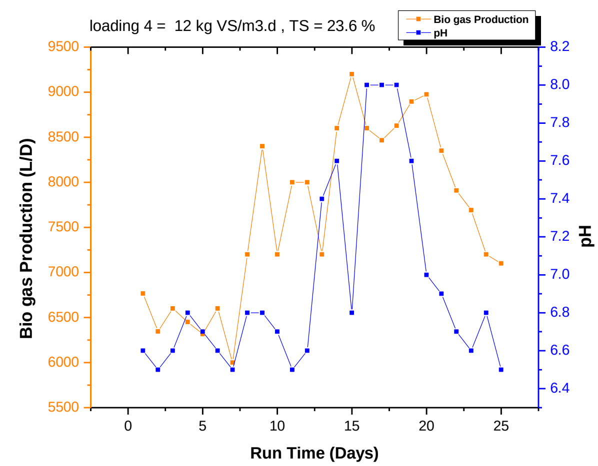

Fig. 3(d).

Fig 3. (a, b, c, d). Showing *Effect of pH on the Daily* Biogas Production for loading L_1, L_2, L_3, L_4.

B. Effect of OLR on concentrations of Constituents of Biogas.

The daily measured CH_4 and Co_2 values are shown in Fig 4. (a, b, c, d). Increased CO_2 in the initial or any stage of anaerobic digestion reveals the deployment of volatile fatty acids, resulting in over-acidity in the Market waste anaerobic fermentation which is evident in the L_1 load. The mean value CH_4 and Co_2 measured were 61.076 %, 38.972 respectively as observed from Fig.4(a). It is because the organic fractions of the market waste mixture were at the initial phase of anaerobic digestion i.e acetogenesis and acidogenesis reaction, it was slowly moving towards methanogenic activity.

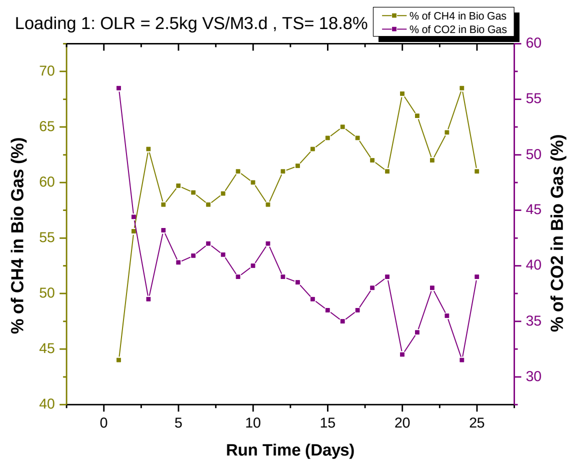

Fig. 4(a).

The digester showed an increase in CH_4 values in loading L_2 and L_3 as shown in Fig.4(b) & Fig.4(c).

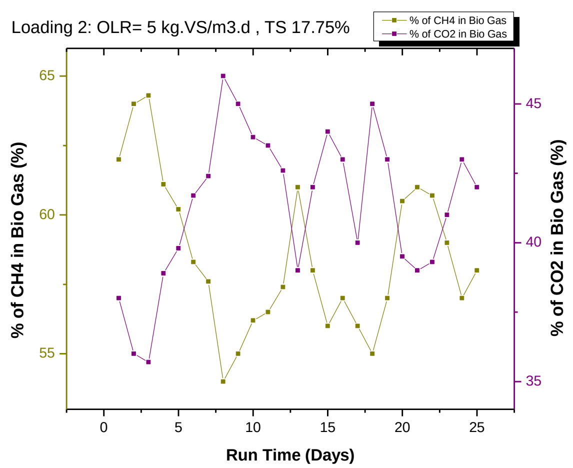

Fig. 4(b).

The quantity organic fractions market waste mixer fed to the digester was less & its well mixed hence it doesn't imbalance the methanogenic phase of AD.

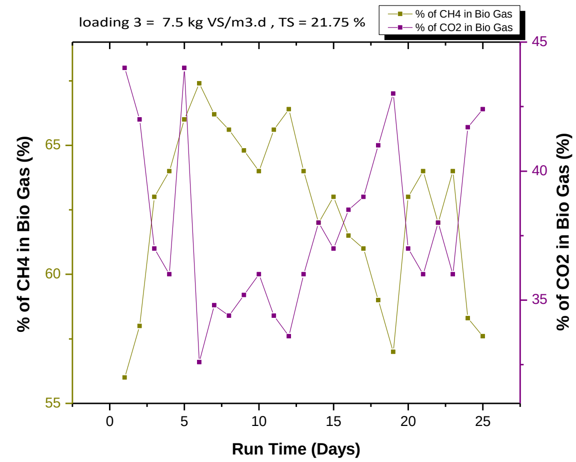

Fig. 4(c).

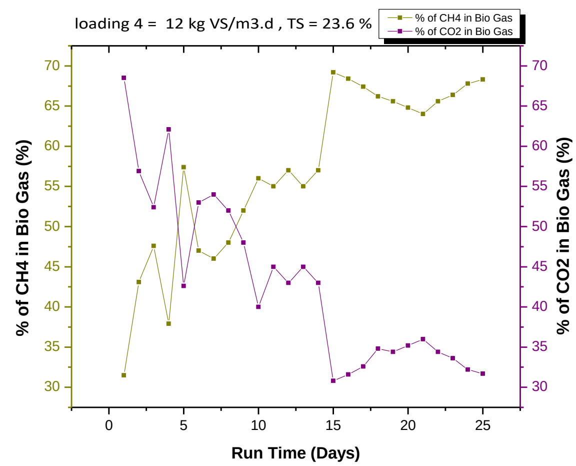

Fig. 4(d).

Fig 4. (a, b, c, d). CH_4 and CO_2 Concentrations (%) for loading L_1, L_2, L_3, L_4.

In the loading L_4, initially, there was sudden fall of CH_4 was noticed and which is due to the accumulation of volatile fatty acids caused mainly because of high total solid content and improper mixing. This issue can be addressed by adjusting VS loading, well within the designated load. The CH_4 level in biogas was significantly raised by increasing OLR, as shown in Fig 4. (d) by an average of CH_4 concentrations. The findings demonstrate that the time taken for the PFD to achieve a stable level was different for each loading. Also, PDF needs more time to be stable, since more time is needed to acclimatize anaerobic microbes to move from acidogenesis to methanogenesis.

C. Effect of Volatile Solid reduction on Specific Biogas Production

In General, the outcomes of this research are when the digester is maintained in a stable condition, the ability of VS reduction improves the AD system and is directly proportional with the OLR for all loading. The maximum Volatile Solid removal efficiency in the AD after stabilization for each loading L_1 L_2, L_3, and L_4 was 63.05 %, 71.66 %, 69.45 %, and 57.46 %, respectively as shown in Fig 5 (a, b, c, d).

Initially, it was noted that the volatile solid removal efficiency was less, as the Digester at starting phase of acetogenesis reaction and once it attains stability it can be observed that the digester well versed with methanogenic reactions as the VS removal efficiency increased notably with increased OLR rates. From the results, the daily biogas generated for the above-said maximum VS removed for each loading, in L_1 is 2112 liters/day, in L_2 is 4493 liters/day, in L_3 is 6910 liters/day and in L_4 is 9200 liters/day was observed and shown in Fig 5 (a, b, c, d).

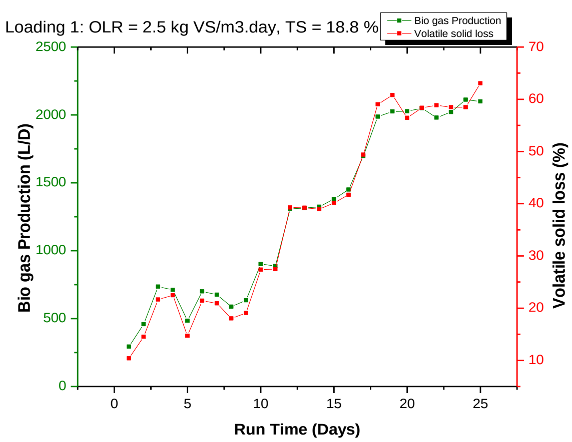

Fig. 5(a).

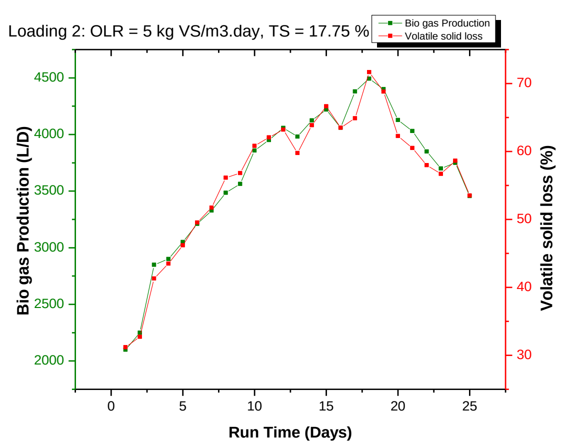

Fig. 5(b).

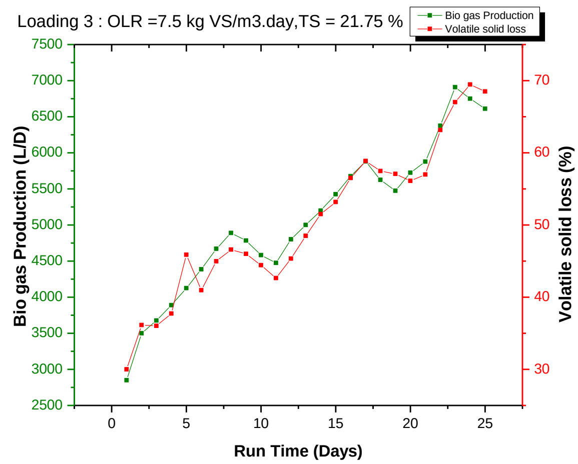

Fig. 5(c).

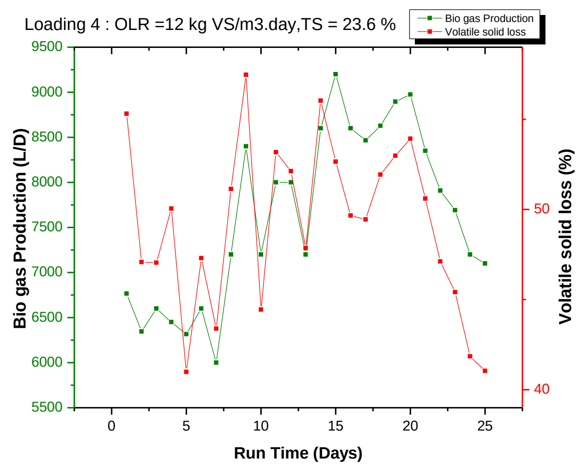

Fig. 5(d).

Fig 5. (a, b, c, d). Biogas Production V/s *Volatile Solid* loss for loading L_1, L_2, L_3, L_4.

D. Effect of Alkalinity and pH

Alkalinity is an absolute necessity for pH management and aids as a shield that averts a quick variation in pH. It is resulted due to the release of amines and the generation of ammonia as the proteinaceous wastes were fermented. Anaerobes, especially methanogens, are sensitive to the acid attentiveness inside PFD, and acidic conditions can inhibit their growth. The variations in pH and alkalinity are shown in Fig 6 (a, b, c, d). Due to the formation of Volatile fatty acids (VFA), the digestate turns acidic pH falls.

The Digester operated in steady-state, for loading L_1 it is observed from the pH variation curve from Fig.6 (a) that there are no many fluctuations in pH. The lower alkalinity value of 2500 g/L as $CaCO_3$ was observed and hence the methanogenic microbial activities were slow, and CH4 concentration was found to be lesser than 50% of AD. The pH of the digestate is enhanced by adding about 2.0 kg Sodium hydroxide (commercial Soda, NaOH), in total on the 2nd, 3rd, 4th days. From the 5th day onwards, pH concentrations almost steady from then biogas production was found stable and produced biogas 2112 liters/day on the 24th day which is shown in Fig 4. (a), with pH being neutral. In any loading and any stage of AD as and when the pH value of the digestate falls below 7 which results in accumulation of VFA's and the system should be brought back by adding the appropriate quantity of Caustic soda to the system. In Loading, there are many fluctuations of pH concentration of the digestate it's well within the methanogenic phase. Higher values of the Total solid content and organic loading rates result in lower values of pH which can be seen in the loading L_3 and L_4, as shown in Fig. 6(c,), (d).

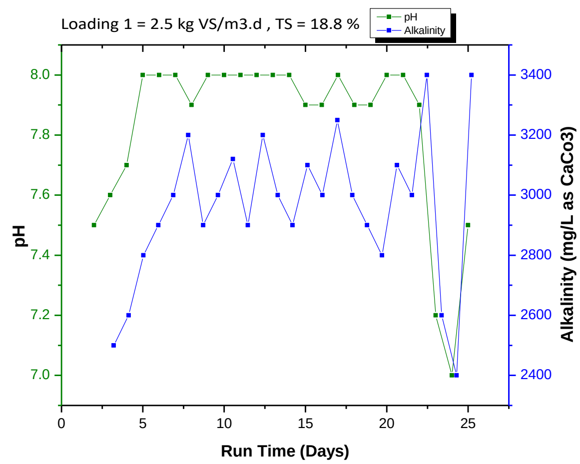

Fig 6. (a).

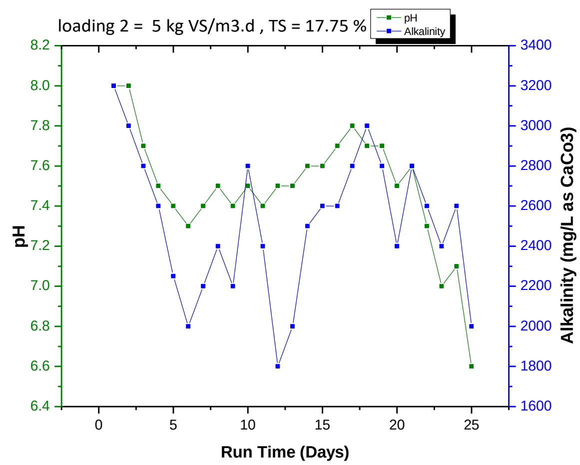

Fig 6. (b).

As OLR increased from 5 kg VS/m^{3}day to 7.5 kg VS/m^{3}day in loading L_3 the concentration pH of AD decreases and attains a value less than 7.0 but still, it will remain in a neutral and favorable methanogenic phase, and hence Methane concentration found to be more than 50%.

The OLR increased from 7.5 kg VS/m3day to 12 kg in L4 with high TS content, it can be observed from Fig. (d) that the pH falls suddenly and it's below 7 and hence the CH4 value found to be less than 50% and the system stopped immediately and brought back to the normalcy by adding NaOH.

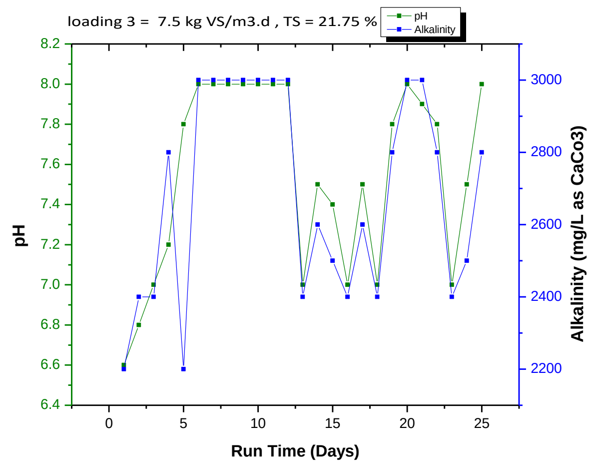

Fig 6. (c).

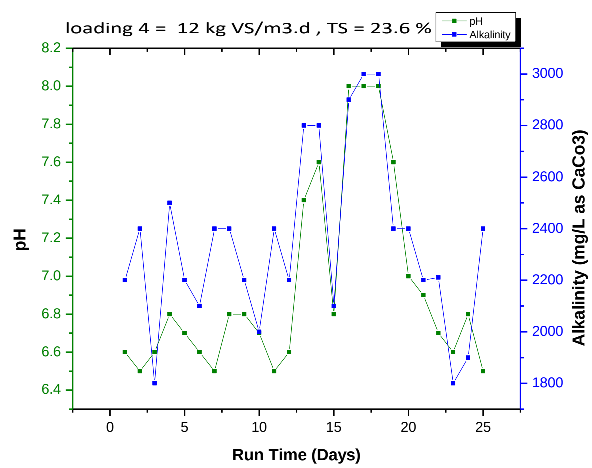

Fig 6. (d).

Fig 6. (a, b, c, d). showing variations of Alkalinity and pH for loading L_1, L_2, L_3, L_4.

IV. CONCLUSIONS

The Anaerobic digestion process investigated for the valorization of Market waste. The Digester operated for continuous Thermophilic mode at a constant thermophilic temperature of 55°C successfully, with FVW mixture ratio fixed at 2.2:2.8 for optimum yield, and then it is co-fermented with food waste and previous digestate with a 2:1:1 inoculum ratio. The HRT is fixed for 25 days for each loading. The variable OLR opted and it is 2.5kg/ m^3.day for loading L_1 and 5 kg/m^3.day for L_2, 7.5 kg/m^3.day for L_3 and 12 kg/m^3.day for L_4 with Total Solid concentration of 18.8, 17.75, 21.75%, and 23.6% for each loading respectively. From the results, it is observed that the maximum specific biogas generated in L_1 is 0.528 m^3/kg, L_2 is 0.562 m^3/kg in L_3 is 0.57583 m^3/kg and in L_4 is 0.47917 m^3/kg per kg of VS removed.

The dry anaerobic digestion process was most significant during the loading L_3 (OLR: 7.5 kg VS/m^3day, TS: 21.75%) than other loadings, the maximum specific biogas 0.57583 m^3/kg was produced per kg VS removed with a 69.5% reduction in VS, 67.4 % CH_4 concentrations.

Acknowledgments

The authors are grateful to the authorities of Visvesvaraya Technological University Belagavi, for their support and encouragement for the smooth conduction of the project.

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