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Assessment of Various Agitation Speeds for Co Digestion Process

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***Abstract:** In the present day context of environmental pollution, the continuous generation of organic wastes and its improper management has been playing a vital role. Current global Municipal Solid Wastes (MSW) generation levels are approximately 1.3 billion tonnes per year and are expected to increase to approximately 2.2 billion tonnes per year by 2025. These wastes have to be properly treated and should be safely disposed. Among the various processing technologies, the anaerobic digestion technology in the form of Co digestion process is the most valuable approach in the waste management sector as it provides a bio fuel and organic rich manure to the society. It requires a good operation technique like mixing in order to maintain the stability of the digester for biogas production. An attempt has been made by utilizing different types of wastes in a lab scale reactor for co digestion process with mixing technique. Kitchen wastes, Poultry Litter and slaughterhouse wastes were used as substrates and fresh cow dung as inoculum. Three Organic Loading rates of 2.5 g VS l/day, 2.68 g VS l/day and 2.83g VS l/day were taken with the hydraulic retention time of 35 days. The mixing was performed through the mixer at various speeds of 30 rpm, 45 rpm, 60rpm and 100 rpm during the co digestion process. When compared to other agitation speeds like 30rpm, 60 rpm and 100rpm, 45 rpm agitation speed performed its digestion upto 80th day with the minimum gas production of 0.1 l/day. The stability of the digester also maintained well with the VFA/Alkalinity ratio of 0.17 on the day of maximum yield and 0.12 at the end of digestion period. The percentage of Total Solids reduction and Volatile solids reduction for 45rpm agitation speed was 51.04% and 55.49% respectively. Hence, the agitation speed of 45rpm had been chosen as the optimum speed for lab scale co digestion process.*

***Key words:** Mixing, substrate, co digestion, agitation, organic loading rate*

I. INTRODUCTION

Current global Municipal Solid Wastes (MSW) generation levels are approximately 1.3 billion tonnes per year and are expected to increase to approximately 2.2 billion tonnes per year by 2025. This represents a significant increase in per capita waste generation rates from 1.2 to 1.42 kg per person per day in the next decade.

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Municipal waste and industrial process wastes, scrap materials, off-specification products, slag and tailings from heavy and light manufacturing industries, refineries, chemical plants, power plants, mineral extraction and processing industries have comparatively significant impact on environment.

As per Shashikanta Keisham and Biswajit Paul, 2015, the improper disposal of the above mentioned wastes may lower the groundwater quality by leachate percolation.

On the other hand, due to open dumping of these wastes may cause air pollution by emission of greenhouse gases. The waste in the dumping yard experiences various anaerobic reactions which further produces offensive Green House gases such as CO2, CH4 etc. These gases are contributing potentially to Global Warming & Climate Change phenomenon. Such dumping activity in many coastal towns has led to heavy metals rapidly leaching into the coastal waters as stated by (Shashikanta Keisham and Biswajit Paul, 2015, Kaushal et al, 2012).

Anaerobic digestion technology is the most valuable approach in the waste management sector as it provides a bio fuel and organic rich manure to the society. Further, the dependency of a single substrate and its availability in adequate manner will not justify the technology as a reliable one. Thus, the anaerobic digestion technology is progressed towards anaerobic co digestion process.

Co digestion is the process in which two or more substrates added together in a homogeneous manner. Co digestion is the most workable option to overcome the difficulties occurs during the single substrate digestion. It also offers improved balance of nutrients and C/N ratio, dilution of toxic substances, readily degradable organics, a better quality of digested products and reduced costs.

Many researchers carried out the experiments on conversion of organic wastes into a advantageous product. Among various technologies, anaerobic digestion technology established a complete awareness throughout the world. Under the absence of Oxygen, different microbial populations degrade organic waste and results in the form of biogas and nutrient rich manure (Azeem Khalid et al, 2011, lastella et al, 2002 and Lata et al, 2002). Besides the gas production, the technology has few drawbacks such as having long retention times and lower percentage removal of organic compounds (Azeem Khalid et al, 2011). High solid wastes always show the rate limiting step of anaerobic digestion process in converting complex substances into simpler ones (Chulwahan et al, 2005 and Mumme et al, 2010). Further it is added that it requires pretreatment facility in physical, Chemical and enzymatic treatment for substrate solubility and step up the degradation of solid organic wastes, (Azeem Khalid et al, 2011, Torres and Lorrens, 2008 and Charles et al, 2009).

In order to improve the yield of biogas, to improve balance of nutrients and to dilute the toxic compounds, experimental studies were further focused as “Co digestion “process. It has been examined that co digestions of mixture of wastes stabilizes the feed to the bio reactor, thereby increasing the carbon to nitrogen ratio (C/N) (Azeem Khalid et al, 2011 and Cuetos et al, 2008). Stimulatory effect on synthesis of methane gas has been observed during the co digestion of industrial sludge and municipal solid wastes (Azeem Khalid et al, 2011 and Agdag and sponza, 2007).

The co digestion process requires good operation techniques to maintain the stability of digestion. Review of various literatures revealed that the mixing is one of the operation techniques to improve the co digestion process and maintain the stability of digestion. Few of the constraints like lack of operation and maintenance, lack of optimum designs, leakages, and scum formation have been reducing the efficiency of the biogas plants in many areas.

Mixing facilitates contact between the microorganisms, the substrate and nutrients and provides a uniform temperature throughout the process. It is particularly important for hydrolytic microorganisms to make good contact with the various molecules that they should digest and that their enzymes can be distributed across a large surface area within the substrate. Mixing also prevents material from accumulating on the bottom of the digestion tank and reduces the risk of foaming.

Mixing also facilitates the important contact and transfer of hydrogen between methane producers and the organisms that carry out anaerobic oxidation. On the other hand, mixing should not to be too strong. Often these microorganisms grow in tight clumps called aggregates, which facilitates their close cooperation and thus the transfer of hydrogen. Gentle mixing benefits the formation of aggregates and prevents methane producers from being washed out in the liquid. Continuous mixing avoids sedimentation and utilizes the existing digestion tank volume in the best manner. Mixing maintains uniformity in substrate concentration, temperature and other environmental factors. It minimizes the formation of scum at the surface and prevents the deposition of solids at the bottom. The degree of mixing varies depending upon the feedstock and operation conditions. Scum formation depends on the feed. The addition of large amounts of fibrous materials and fats results in the formation of a scum layer. If the organic materials are in the scum layer, they will not be available as feed to the organisms degrading the materials to gas. Thus the gas production rates in a digester with scum layers are reduced. Mixing in the substrate tank is also important to avoid sedimentation and thus uneven loading of the digestion tank (Anna Schunerur and Asa Jarvis, 2009).

Mixing can be accomplished through mechanical methods or gas recirculation. These methods include external pumps, gas injection or recirculation from the floor or roof of the digester, propellers or turbines and draft tubes. Mechanical mixers are more effective than gas recirculation, but they often become clogged or folded with digester solids. Mixing need not be continuous to achieve acceptable volatile solids destruction. Continuous mixing is costly and requires a facility that will enhance the separation of digested solids from the liquid phase. Routine mixing of digester content, for example, three to six periods of mixing per day of 1 to 3 hours duration for each mixing period, may be an efficient alternate to continuous mixing as per Michael H.Gerardi, 2003.

Mixing eliminates thermal stratification or localized pockets of depressed temperature. It maintains the physical and chemical uniformity of the sludge throughout the tank. The rapid dispersion of metabolic wastes will be stimulated by mixing action during substrate digestion. It minimizes the toxicity and prevents the deposition of grit (Kangle et al, 2012).

Nevertheless excessive mixing can upset the microorganisms and therefore slow mixing is desired. During co digestion process, in order to bring sufficient homogeneity, the different feedstocks should be mixed (Fabien Monnet, 2003).

El-Bakhshwan et al, 2015 investigated the effect of mechanical stirring with different speeds and various stirring periods in large scale biogas digesters of 2 numbers of fixed dome digesters with total volume of 20 cubic metre. The experiment was conducted with three stirring speeds of 30, 45 and 60 rpm and four stirring periods of 15 min/hr, 15min/2hr, 15min/3hr and 15 min/4hr. The performance of the stirring speed in the experiment proved that 60 rpm which gave the high values of biogas production at the rate of 0.423 m^3/m^2/day.

Khursheed Karim et al, 2005 conducted the anaerobic digestion experiment in eight numbers of laboratory scale digesters and studied the effect of various modes of mixing like biogas recirculation, impeller mixing and slurry recirculation and waste strength. the effect of mixing showed the prominent results due to mixing and mode of mixing in 10% thicker slurry. The unmixed digester with 10% slurry contributed the least biogas production.

Hence, the present study focused towards the utilization of multiple substrates in the co digestion process in a lab scale reactor for biogas production. In addition to that, the possibility of operation technique like mixing (agitation) was evaluated through the following objectives

i. To establish the optimum mixing speed through semi continuous stirred tank reactor with various Organic Loading Rates.
ii. To evaluate the operation performance of the anaerobic reactor treating different types of wastes

II. EXPERIMENTAL WORK

A. Kitchen Wastes

For the experimental work the food wastes and vegetable wastes were collected from the Hostel and Canteen points of Periyar Maniammai University, Thanjavur. The Kitchen wastes include leftover food (Rice, Idli, Dosa, Bread and rotis), Vegetable peelings and vegetable wastes (Brinjal, Potato, Carrots, Pumpkin, raddish, etc). In order to know the compositional variability of the kitchen waste it was decided to collect the waste continuously for one week. Samples were collected from the hostels for all seven days and for 5 working days from the canteen. These kitchen wastes were examined to remove the unwanted materials and grinded in a normal mixer grinder and the pulpy material was taken and stored at 4°C prior to analysis and experiment.

B. Slaughterhouse waste

Slaughterhouse wastes were collected from beef stalls and mutton stalls in Thanjavur Corporation, Tamilnadu. These wastes include non edible portions of flesh and particles of skins and tissues. These wastes were collected and examined to remove bone materials. Finally the segregated slaughter house wastes were minced to a fine semi solid substance. The fleshy pulp also stored under 4°C before analysis and experimental work.

C. Poultry litter

Poultry litter was collected from Periyar Poultry Farm, Siruganur, Trichy District, Tamilnadu. It was collected and screened for the removal of unwanted materials. The collected material was in the powdered form and dry granules. The poultry litter slurry was prepared by adding distilled water added to the dry granules and allowed for acclimatization. The acclimatized slurry was fed to co digestion process.

D. Lab scale Reactor

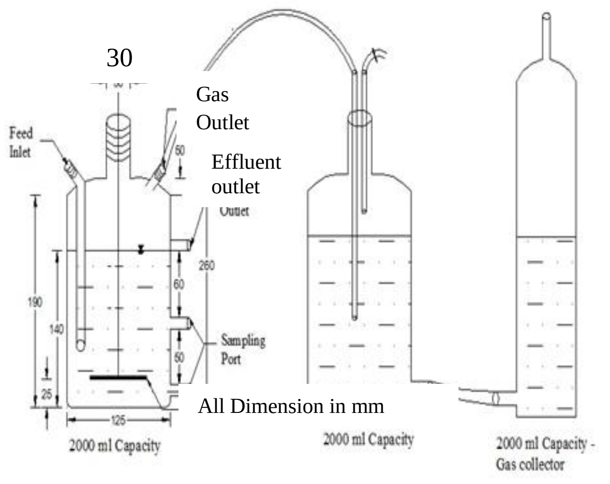

Figure 1: Layout of fabricated lab scale anaerobic digester planned for conducting experiments

The experiments were conducted with 2 litre capacity reactor as shown in figure 1.The reactor was fitted with stirrer to agitate the contents in order to bring homogeneity of the substrates. Agitation was carried out in semi continuous mode. The hydraulic Retention time maintained for all the cases was 35 days. The co digestion process was carried out under mesophilic temperature between 25°C and 39°C. Biogas production was measured through water displacement method

The experiment conditions are taken such as

- The substrates were added in a homogeneous manner with mixing ratios of KW: SHW: PL(1:1:1).
- The contents were mixed in order to maintain 10% of Total solid concentration. Initially the anaerobic digester was flushed with anaerobic gas, methane and all the openings were closed and maintained for 10 to 15 minutes in order to develop anaerobic condition inside the digester. It was fed with fresh cow dung as Inoculum for the volume of 1600ml for the start up of the reactor.
- After the evolution of gas during start up period, 800 ml of cow dung was replaced with the homogeneously mixed substrate slurry.
- The remaining space in the digester was left for the accumulation of gas.
- The hydraulic retention time was maintained for 35 days.
- Three Organic Loading rates of 2.5 g VS l/day, 2.68 g VS l/day and 2.83g VS l/day were taken.

The experiment was intended to determine the desirable mixing speed for the removal of scum and to maintain homogeneity in the anaerobic digester. In this experiment, the mixing was performed through the mixer at various speeds of 30 rpm, 45 rpm, 60rpm and 100 rpm. All the mixing speed was done under semi continuous mode. The mixing was carried out for 20 minutes for 5 times a day. The parameters like pH, Total solids, Volatile solids, Chemical Oxygen Demand and gas production were measured in accordance with APHA, 1998.The optimum mixing speed was observed at which the maximum gas production was generated.

III. RESULTS AND DISCUSSION

A. pH Profile

During co digestion process, different agitation speeds were given to the ingredients in the digester. Profiles of pH were discussed for various speeds of agitation as shown in the figure 2. Under the agitation of 30 rpm, the pH values were between 6.5 and 7.5 in the first organic loading rate of 2.5gVS/L/day.

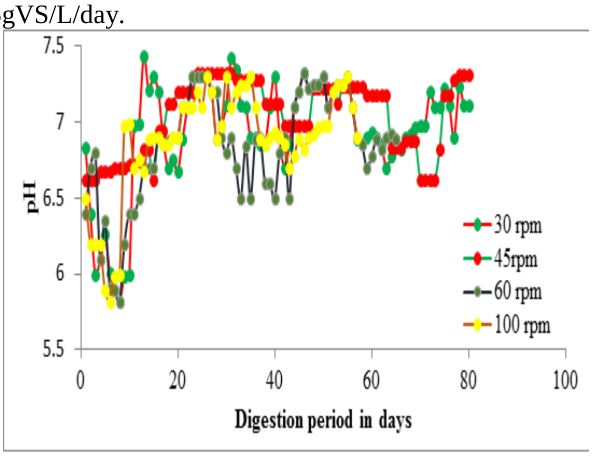

Figure 2: pH profile for various agitations

The pH values for different speeds 45 rpm, 60 rpm and 100 rpm were between 6 and 7 in the initial organic loading rate. During second organic loading rate of 2.68 gVS/L/day, the 60 rpm performed to produce the range of pH values within 6.5 to 6.89 with more fluctuations and attained the maximum pH of 7.32. The profile of 30 and 60 rpm were similar during second organic loading rate.

During third organic loading rate of 2.83 gVS/L/day, only for agitation speed of 30 and 45 rpm exhibited similar profile and attained the maximum value of 7.31. However, the profile of agitation speed of 45 rpm showed the maximum value of 7.43 and maintained the stability between 25th day and 33rd day.

B.VFA/Alkalinity ratio

The ratio of Volatile Fatty Acids/Total alkalinity (VFA/TA) indicates the stability of the digester. When the ratio is less than 0.3, it indicates stability and 0.3 to 0.5 noted as the digester is experiencing stability to lesser extent. The instability and the failure of the digester will occur whenever the VFA/TA ratio is more than 0.5.

The stability of the digester has been narrated according to the pattern shown in the figure.3.

The digester when experimented with agitation speed of 30 rpm explored the VFA/ TA range from 0.2 to 0.475 for initial OLR of 2.5 gVS/L/day and maximum of 0.41 for second OLR of 2.68 gVS/L/day and the lowest value of 0.26 for Third OLR of 2.83 gVS/L/day. Under agitation speed of 45 rpm, the digester maintained the stability conditions with the range of 0.45 to 0.18.In most of the digestion period the digester showed the VFA/TA ratio within 0.17 and 0.18 under agitation speed of 45 rpm.

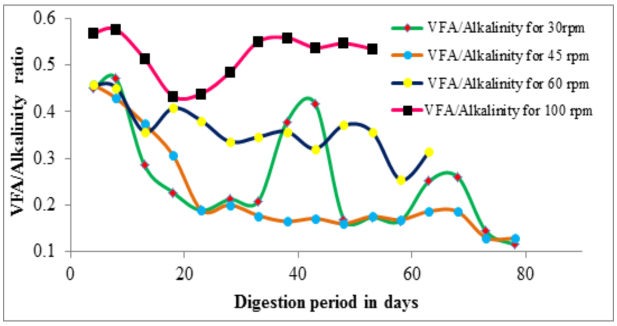

Figure 3: VFA/Alkalinity ratios for various agitations

During 60 rpm agitation speed the VFA/TA ratios were from 0.45 to 0.27 and projected the maximum of 0.37 during second organic loading rate. For the agitation speed of 100 rpm the instability conditions prevailed with ratios of 0.56 to 0.53.The instability started during second OLR of 2.68 gVS/L/day and never progressed for third OLR of 2.83 gVS/L/day. It was observed from the experimental results that the remarkable stability and the maximum gas production occurred under agitation speed of 45 rpm.

C. Chemical Oxygen Demand (COD)

The reduction of COD from the initial phase of the digestion to the end phase of the digestion for all agitating conditions was shown in the figure.4. Under 30 rpm agitation speed, the profile of COD started from 43756 mg/l and ended at 8224 mg/l. The gradual decrease in COD value was observed for 45 rpm agitation speed and reduced up to 5062 mg/l. The performance of the digester in COD reduction under 60 rpm had experienced the gradual reduction of COD and ended up to 11062 mg/l. The agitation speed of 100 rpm exhibited very less reduction in COD and there was no further reduction of COD after the period of Second OLR. When compared with all the agitation conditions the 45 rpm agitation speed showed the remarkable COD reduction for every phase of the organic loading rate.

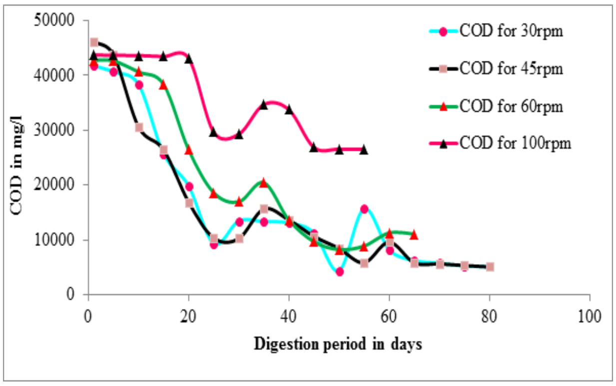

Figure 4: Chemical Oxygen Demand for various agitations

D. Methane generation

The performance of the digester was analyzed for various agitating conditions such as 30 rpm, 45 rpm, 60 rpm and 100 rpm as shown in the figure 5. The profile of 30 rpm agitation speed exhibited unstable condition during the initial organic loading rate of 2.5 gVS/L/day and yielded 0.11 l of methane on 42nd day in second organic loading rate of 2.68 gVS/L/day and also related to very less yield of 0.105 l in third organic loading rate of 2.83gVS/L/day.

For initial organic loading rate, the maximum yield of 0.45 l methane was attained and the stability was maintained for 3 days while mixing with 45 rpm agitation speed. The stability was maintained for few days and also reached the peak value of 0.485 l of methane in the third organic loading rate of 2.83 gVS/L/day.

It is noted that at 45 rpm, maximum yield and few stability periods were observed during all the three organic loading rates.

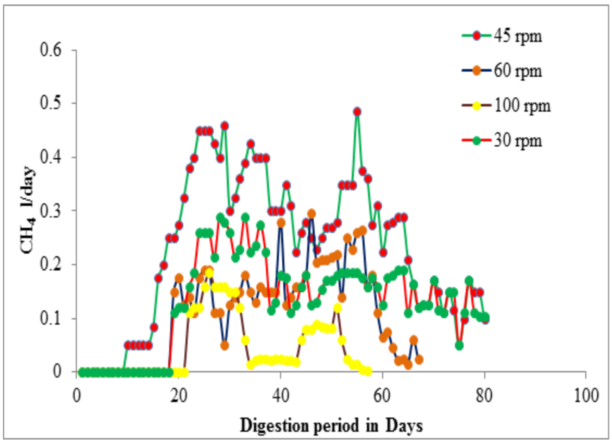

Figure 5: Methane generation under various agitating conditions

E.Total and Volatile solids concentration

The co digestion process was started with 10.82 % of Total solids in the digester under 30 rpm agitation speed. The concentration of Total solids got reduced when the volatile organic matter transformed into gaseous matter which is shown in the figure.6. The continuous digestion removed the total solids and volatile solids gradually. In Second OLR, 2.68 gVS/L/day, the TS concentration was maintained for about 10.63%.and finally it got reduced to 6.36% on 80thday.

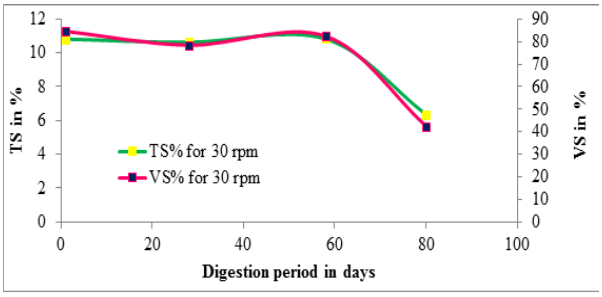

Figure 6: Total Solids and Volatile Solids concentration for 30 rpm

The experiment started with volatile solids of about 84.62% of TS.

Gradual degradation of Volatile solids was happened during the co digestion process. After the completion of digestion period, the volatile solids were degraded to 42.49%

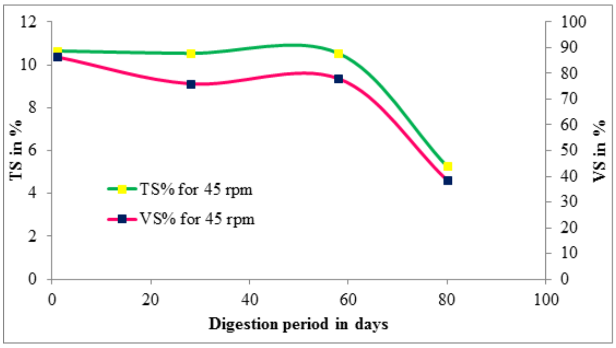

Figure 7: Total Solids and Volatile Solids concentration for 45 rpm

The co digestion process started with TS concentration of 10.65% under 45 rpm agitation. Similarly second OLR of 2.68 gVS/L/day and third OLR of 2.83 gVS/L/day were supplied to the digester and the TS concentration was maintained of about 10.538% and slowly degraded and ended with the concentration of 5.26% as shown in the figure.7. With the concentration of 86.42% of VS, initial OLR of 2.5 gVS/L/day was applied to the digester. The performance of the digester during 45 rpm agitation made the co digestion process viable and reduced the total solids concentration of 5.26% and Volatile Solids concentration of 38.46% at the end of the process.

During 60 rpm agitation speed, about 10.02% of Total Solids concentration was maintained for initial phase of digestion with first OLR of 2.5 gVS/L/day .Between the period of initial OLR of 2.5 gVS/L/day and Second OLR of 2.68 gVS/L/day the total solids got reduced which is shown in the figure.8. During the stage of second OLR of 2.68 gVS/L/day and third OLR of 2.83 gVS/l/day the TS was maintained as 10.62% and 10.82% respectively. The Volatile solids degraded more rapidly than30 rpm and 45 rpm agitation. The degradation of VS for second OLR of 2.68 gVS/l/day and third OLR of 2.83 gVS/L/day were observed as 81.08% and 75.63% respectively. The final effluent of the digester showed the concentration of volatile solids as 46.82% which was slightly more than the degradation occurred for 45 rpm agitation speed.

During 100 rpm agitation speed, the TS concentration was maintained as 10.11% and the Volatile solid concentration as 85.48% for the co digestion process. The degradation of Volatile solids under high agitation speed of 100 rpm experienced the lesser degradation of Volatile solids in both second OLR of 2.5 gVS/L/day and third OLR of 2.68 gVS/L/day which is shown in the figure.9.

The Volatile solids in the effluent were observed as 48.62%. However the digester performance in gas production was reduced after the second OLR of 2.68 gVS/L/day and third OLR of 2.83 gVS/L/day with 100 rpm agitation speed.

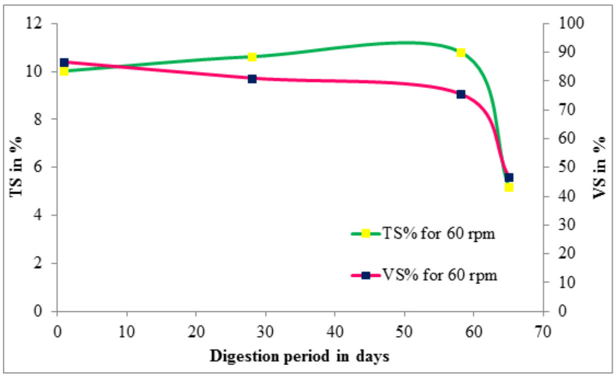

Figure 8: Total Solids and Volatile Solids concentration for 60 rpm

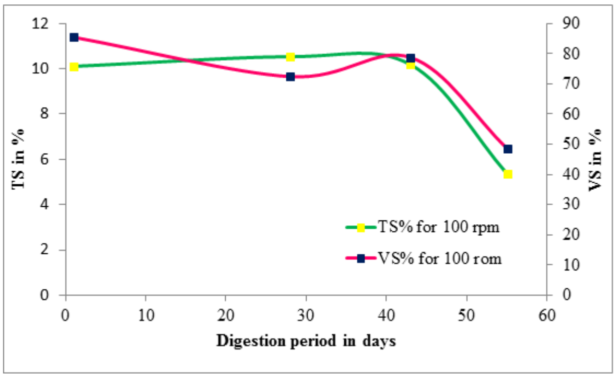

Figure 9: Total Solids and Volatile Solids concentration for 100 rpm

Table 1: Parameters which occur during the maximum gas production under agitation operations

Parameters	Various agitating conditions							
	30 rpm		45 rpm		60 rpm		100 rpm	
	Max	Min	Max	Min	Max	Min	Max	Min
Methane (l/day)	0.29	0.105	0.485	0.1	0.295	0.025	0.19	0.0025
pH	7.28	7.11	7.24	7.31	7.32	6.89	7.3	6.9
COD (mg/l)	13325	5134	5834	5062	9682	11062	29652	26534
VFA/ Alkali	0.2	0.1	0.1	0.1	0.43	0.3	0.48	0.53

nity (mg/l)		1	7	2	7	1		
TS (influent) (%)	10.82		10.65		10.02		10.11	
TS (effluent) (%)	6.36		5.26		5.18		5.36	
VS (influent) (%)	84.62		86.42		86.67		85.48	
VS (effluent) (%)	42.49		38.46		46.82		48.62	

Table 2: Cumulative methane for various agitation speeds

Details	30rpm	45 rpm	60 rpm	100rpm
Cumulative methane (l)	10.58	18.47	7.33	2.67
Digestion period (Days)	80	80	67	57

It was observed that maximum methane of 0.29 l/day for 30rpm on 33rd day as per table 1. However the 100 rpm agitation speed attained the maximum methane as 0.19 l on 26th day of its digestion period, then the gas production descended further. Similar maximum methane yield of 0.295 l was observed for 60 rpm agitation speed on 46th day. On the other hand, the digestion period for 60 rpm agitation speed was completed 13 days earlier than 30rpm agitation speed. The maximum methane production was observed as 0.485 l on 55th day for 45rpm agitation speed. Maximum cumulative methane production was observed as 18.47 l as per table 2.

IV. CONCLUSION

When compared to other agitation speeds like 30rpm, 60 rpm and 100rpm, 45 rpm agitation speed performed its digestion upto 80th day with the minimum gas production of 0.1 l/day. The stability of the digester also maintained well with the VFA/Alkalinity ratio of 0.17 on the day of maximum yield and 0.12 at the end of digestion period. The percentage of Total Solids reduction and Volatile solids reduction for 45rpm agitation speed was 51.04% and 55.49% respectively. Similar VS reduction was observed for 30rpm, 60rpm and 100rpm exhibited as 49.78%, 45.97% and 43.12% respectively. Conversely, the maximum reduction of COD was observed as 5834mg/l on the day of maximum yield. Considering all the parameters, the agitation speed of 45 rpm performed with maximum methane yield and better stability. Hence, the agitation speed of 45rpm had been chosen as the optimum speed for lab scale co digestion process. Further, the research has to be extended to increase the methane yield through various pretreatment methods and enhancement techniques.

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