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Alkali Pretreatment of Paper Mill Sludge to Enhance Biogas Production

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ABSTRACT

The aim of this study is to analyze the potential to enhance biogas production from papermill sludge by the use of alkali pretreatment. The pH of the initial samples were in the range of7.25 – 7.63 and that of final slurry samples were 6.5 – 7.0.The total solid and volatile solid content for raw paper mill sludge and pretreated papermill sludge were found to be 37.2%, 18.90% and 60.98%, 50.47% respectively. In laboratory experiments, the maximum total gas production was observed in 75% pretreated paper mill sludge substitution with the minimum and maximum total gas production was 75,090 ml and 79,340 ml respectively. For field experiments, the maximum gas production of 252 liter/kg dry matter was recorded in 90% alkali pretreated paper mill sludge substitution. It is clear that alkali/NaOH pretreatment enhance the biogas production and effectively utilized the paper mill sludge up to 90% replacement from 60% (Untreated PMS), which shows that alkali pretreatment could be an effective method for improving methane yield in paper mill sludge.

Introduction

Pulp and paper industry are one of the most polluting, energy and water intensive industries in the world. Produced pulp and paper mill sludge (PPMS) faces a major problem for handling and its management. An anaerobic digestion has become an alternative source. Anaerobic digestion (AD) of solid organic waste has gained increased attention as a means of producing energy-rich biogas, destructing pathogenic organisms and reducing problems associated with the disposal of organic waste. Paper mill sludge is produced in the mill's wastewater treatment process. An alternative is to use anaerobic digestion on the sludge and by doing so extract renewable energy in the form of biogas. Furthermore, the paper industries have some processes that currently require fossil fuels, for which biogas or pure methane could become a renewable fuel alternative and thus make the mills less dependent on fossil fuels.

Using paper mill sludge as a biogas substrate would promote the sustainable development of society, turn waste into raw material, and be in line with current bio-economic thinking. Pre-treatment can be used to reduce the necessary retention time to produce biogas. For example, certain processes shred the substrates to increase the surface area or use a thermal pre-treatment stage to significantly enhance the biogas output. The thermal treatment can also be used to reduce the pathogenic concentration in the digestate. The aim of pre-treatment of sludge is to lyse the cell structures, which benefits especially the first step of the methane production process, the hydrolysis. Anaerobic digestion is a process driven by bacteria in an oxygen-free environment. The process is divided into three steps—hydrolysis, fermentation and methane production—in which the macromolecules are cleaved, and acid, acetate and methane are formed. In industrial anaerobic digestion, the temperature is usually between 30-40 ^{o}C or 40-60^{o}C, depending on whether the bacterial culture is mesophilic or thermophilic. Mesophilic digestion is more stable and demands less added heat, whereas, thermophilic digestion is faster as increased temperature increase reaction rates. Possibly mesophilic digestion in combination with pre-treatment could be a suitable compromise. Anaerobic digestion is most often considered to berate limited by the hydrolysis and cell lysis stages. Various sludge disintegration methods have been studied for pre-treatment purposes in order to increase the rate of methane production, including thermal, chemical, mechanical and biological methods. With paper mill sludge, increased methane yields under mesophilic conditions have been reported from alkali, microwave, hydrothermal and ultrasound pre-treatments (Wood, N *et al.*, 2009, Saha, M *et al., 2011).*

The most studied chemical pre-treatment is the addition of sodium hydroxide (NaOH). Other bases studied include potassium hydroxide (KOH), magnesium hydroxide ($Mg(OH)_2$) and calcium hydroxide ($Ca(OH)_2$). Sodium hydroxide has been shown to have a very positive effect, often in combination with thermal pre-treatment, though high concentrations of 10 g NaOH/L can cause the formation of persistent compounds. An alkali pre-treatment process using sodium hydroxide solution showed an optimal concentration of 8 g NaOH/100 g TS sludge (total solids of the sludge) with a methane yield of 0.32 m^3/kg VS removal (volatile solids removed by anaerobic digestion) which was 183% of the control (Lin, Y. Q., 2009). The disadvantages with sodium hydroxide are cost and environmental hazard. Calcium hydroxide, also known as lime, has a cost of only 6%of the price of lye and is easier to handle, which makes it interesting as a base pre-treatment method (Hu and Ragauskas, 2012). Acid pre-treatment gives an increased solubility of the particles in the sludge, though acidic pre-treatments may, however, produce compounds that can cause inhibition and/or be toxic to methane producing anaerobic microorganisms (Galbe and Zacchi, 2012). Alkali addition has been shown to increase solubilization of PPMS and improve biogas yield (Park *et al.*, 2012).

This study aimed to analyze the potential to enhance biogas production from papermill sludge by the use of pretreatments and to find out the optimum percentage of substitution of pretreated paper mill sludge for maximum biogas production.

Materials and Methods

Paper mill sludge was collected from paper mill industry, which is located at 50 km distance from research station. Sludge is the solid residue formed during wastewater treatment (mixed with water). Disposal of solid organic waste (especially if it is wet) is expensive, whereas thermal destruction is both expensive and energy-demanding. Efforts have therefore been made to minimize the production of sludge by using advanced biological treatment processes. Two types of sludge materials are disposed off daily from the mill. One type of sludge contains 50%

organic material and 50% inorganic material. Other type of sludge contains 20% organic material and 80% inorganic material. Hence, the investigation was carried out using the first type (50:50) sludge.

Pretreatment disintegrate the floc structure of sludge and extract both intracellular and extracellular materials, which enhances the biogas production. Paper mill sludge was treated with sodium hydroxide, sodium bicarbonate, sodium hypo-chloride, calcium hydroxide and kept aside for 24 hours. The structure of the substrate remains unchanged except sodium hydroxide. Treatment with 0.5N, 1N, 1.5N and 2N sodium hydroxide caused changes in the structure of the paper mill sludge but the pH was above 9.6. This pH 9.6 is not suitable for biogas production. There is a reduction in pH was observed when 0.01N sodium hydroxide was used with paper mill sludge with cow dung. Therefore, 0.01 N sodium hydroxide can be used for paper mill sludge. This treated paper mill sludge when mixed with cow dung, the reduction in pH was well suitable for biogas production. Therefore, 0.01 N sodium hydroxide is used for alkali pretreatment.

Laboratory experiment

The paper mill sludge was collected from paper mill industry to determine the optimum percentage of paper mill sludge to be added with cow dung as feedstock. The laboratory batch fed fermentation setup was maintained in 5 liters Hofkins flask. The biochemical constituents of raw sludge and pretreated paper mill sludge were analyzed. Based on the chemical constituents of pretreated paper mill sludge, the experimental design was formulated to study the quantity of biogas production from paper mill sludge supplemented with cow dung as given in the Table1.

The laboratory experiments on batch fermentation were carried out in 5 litre Hofkin flasks with various proportions. The experimental setup was maintained for a period of 60 days. The batch 1 and 2 laboratory experiments were completed and the samples were taken for analysis. For each laboratory setup, the initial and final samples were drawn from the flask and the biochemical constituents such as pH, volatile fatty acids, total solids, volatile solids, organic carbon, nitrogen, phosphorus, potassium, sodium were analyzed. Daily gas production was also recorded using water displacement method.

Field experiment

After completion of laboratory experiments, the field experiment was carried out in 2 cu.m. KVIC biogas plants located at ICAR research centre, Courtallam. The experimental design for field experiment is given in Table 2. Field experiment was conducted in 2 m^3 KVIC biogas plant with various combinations of alkali pretreated paper mill sludge along with cow dung simultaneously control was monitored with only cow dung as shown in Fig. 1&2. Paper mill sludge treated with 0.01 N sodium hydroxide is kept aside for 48 hours and after that this alkali treated paper mill sludge was mixed with cow dung in various combinations for biogas production and fed into the biogas plant.

Biochemical parameters of each field experiments, the slurry samples were taken weekly both at the initial and final stage of the experiment. Gas production was also recorded using gas flow meter with 75 - 100% replacement in the treatment plant. The samples of inlet and outlet of control plant and treatment plant were taken every week and the biochemical constituents such as pH, volatile fatty acids, total solids, volatile solids, organic carbon, nitrogen, sodium, potassium and phosphorous were analyzed for each samples.

Analytical methods

The biochemical constituents of the raw paper mill sludge, initial and final slurry samples were analyzed. The pH of the slurry samples were estimated using systronic digital pH meter. The dry matter content of the samples was estimated by complete drying and successive weighing till constant weight is achieved (APHA, 1975). Nitrogen was estimated using micro Kjeldhal methods of Jackson (1958), Phosphorus was estimated by the method of Fiske and Subbarow (1925). Potassium and Sodium were measured by flame photometric method given in APHA (1975). Organic carbon was estimated by the method of Black *et al* (1965).The Cellulose and Hemi cellulose were determined by the method given by Updegraff (1969) and Horwitz (1960) respectively. Lignin content was estimated by the method given in DST-MACS Training Course Manual (1984). In field studies, daily gas production was recorded using gas flow meter. Statistical analysis was carried out according to the method given by Snedecor and Cochran (1967).

Results and Discussion

The biochemical constituents of raw paper mill sludge and pretreated paper mill sludge are given in Table3. The total solid and volatile solid content for raw paper mill sludge and pretreated papermill sludge were found to be 37.2%, 18.90% and 60.98%, 50.47% respectively. According to Gijzen *et al.*, 1990, the total solids of paper mill sludge was 39.8 % and volatile solids was 42.6 %. These values are comparable with the results of biochemical composition of paper mill sludge in the present study.

As reported by Lin *et al.,* 2013, the organic carbon and total nitrogen content in paper mill sludge was 34.75 % and 1.12 %, which is nearly matched with the results of present analysis. As reported in literature, the range of C:N ratio of 20:1 to 30:1 materials can be used as a substrate for biogas production. The C:N ratio of paper mill sludge was found to be 21.43 and pretreated paper mill sludge was 21.09, which makes it suitable as a substitute for cow dung in biogas production.

Laboratory experiments

The biochemical constituents of pretreated paper mill sludge and cow dung slurry samples of initial and final samples are given in Table 4. The operational pH of the anaerobic digestion affects the digestive process. The fermentation microorganisms can function in the range of 4 - 8.5 (Hwang *et al.*, 2004). The ideal pH range for anaerobic digestion has been reported as 6.8 - 7.4. (Igoni, 2003). The pH of the slurry samples before and after digestion of each batches were recorded. The pH of the initial slurry samples were in the range of 7.25 – 7.63 and that of final slurry samples were 6.5 – 7.0. In the initial phase of anaerobic digestion process, the production of Volatile fatty acids (VFA) decreases the pH of the slurry. But the reaction of CO_2 which is soluble in water with hydroxide ion forming bicarbonate ions, so forming HCO_3, tends to restore the neutrality of the process pH. When rate of acid formation exceeds the rate of breakdown to methane, the process imbalance which results in pH decrease.

There is a reasonable reduction in total solids and volatile solid content of final slurry samples in all treatments (Table. 4). This reduction in the total solids and volatile solids at the final stage of experiment indicates the effective utilization of the substrate, which is reflected in the gas production.

Table.1 Experimental Design for pretreated paper mill sludge with cow dung for biogas production

S. No.	Setup	Proportions
Batch 1		
1.	Control	Cow dung alone
2.	Treatment I	25% Tr. Paper mill sludge + 75% cow dung
3.	Treatment II	50% Tr. Paper mill sludge + 50% cow dung
4.	Treatment III	75% Tr. Paper mill sludge + 25% cow dung
5.	Treatment IV	100% Tr. Paper mill sludge
Batch 2		
1.	Control	Cow dung alone
2.	Treatment I	25% Tr. Paper mill sludge + 75% cow dung
3.	Treatment II	50% Tr. Paper mill sludge + 50% cow dung
4.	Treatment III	75% Tr. Paper mill sludge + 25% cow dung
5.	Treatment IV	100% Tr. Paper mill sludge

*Tr – Treated with 0.01 N sodium hydroxide

Table.2 Experimental design for field experiments

S. No.	Setup	Combination
1.	Control	Cow dung alone
2.	Treatment I	75% Alkali *TrPaper mill sludge + 25% cow dung
3.	Treatment II	80% Alkali *Tr Paper mill sludge + 20% cow dung
4.	Treatment III	90% Alkali *Tr Paper mill sludge + 10% cow dung
5.	Treatment IV	100% Alkali *Tr Paper mill sludge

Tr – Treated with 0.01 N sodium hydroxide

Table.3 Biochemical composition of paper mill sludge (50:50) and pretreated paper mill sludge

S.No.	Constituents	Raw paper mill sludge, %	Pretreated paper mill sludge, %
1.	pH	9.0	7.5
2.	Total Solids	37.2	18.90
3.	Volatile Solids	60.98	50.47
4.	Organic Carbon	28.50	24.68
5.	Nitrogen	1.39	1.17
6.	Phosphorous	0.568	0.760
7.	Potassium	0.240	0.218
8.	Sodium	0.770	0.640
9.	Cellulose	12.81	9.67
10.	Hemi cellulose	2.86	2.07
11.	Lignin	5.93	4.99

Table.4 Effect of chemically treated paper mill sludge and cattle dung in various combinations on biochemical constituents of initial and final slurry samples

S. No.	Treatments	pH	VFA mg/litre as acetic acid	Total Solids %	Volatile solids %	Organic Carbon %	Nitrogen %	Phosphorus %	Potassium %	Sodium %
Initial										
1.	Cow dung alone	7.25	312	10.01	79.04	31.5	1.47	1.044	1.41	2.78
2.	25% Tr. Paper mill sludge + 75% cow dung	7.25	240	10.06	69.75	29.8	1.36	0.968	2.06	0.99
3.	50% Tr. Paper mill sludge + 50% cow dung	7.30	197	10.03	63.69	28.5	1.21	0.584	2.39	1.43
4.	75% Tr. Paper mill sludge + 25% cow dung	7.50	249	10.05	63.73	29.1	1.05	0.322	2.57	1.74
5.	100% Tr. Paper mill sludge	7.63	257	10.09	65.93	28.20	1.01	0.256	2.73	1.99
Final										
1.	Cow dung alone	7.0	720	6.70	69.07	28.5	1.05	1.336	1.16	0.88
2.	25% Tr. Paper mill sludge + 75% cow dung	6.58	960	5.18	63.10	26.7	0.78	1.244	1.34	1.35
3.	50% Tr. Paper mill sludge + 50% cow dung	6.50	744	5.41	59.8	25.8	0.74	0.872	2.26	1.28
4.	75% Tr. Paper mill sludge + 25% cow dung	6.78	888	5.82	56.63	24.6	0.66	0.444	2.46	1.67
5.	100% Tr. Paper mill sludge	7.0	936	6.65	57.94	22.50	0.54	0.288	2.49	1.78

Table.5 Effect of chemically treated papermill sludge mixed with cow dung in various proportions on biogas production

S. No.	Treatments	Total Solids, %	Gas Production, litre/kg of dry matter	Temperature, °C	
				Min.	Max.
1.	Cow dung alone	10.01	187.54	28	31
2.	25% Tr. Paper mill sludge + 75% cow dung	10.06	190.63	28	31
3.	50% Tr. Paper mill sludge + 50% cow dung	10.03	195.44	28	31
4.	75% Tr. Paper mill sludge + 25% cow dung	10.05	197.36	28	31
5.	100% Tr. Paper mill sludge	10.09	178.58	28	31

Table.6 Effect of chemically treated paper mill sludge mixed with cow dung in various proportions on weekly gas production – Laboratory study

S.No.	Week	Cow dung alone	25% Tr. Paper mill sludge + 75% cow dung	50% Tr. Paper mill sludge + 50% cow dung	75% Tr. Paper mill sludge + 25% cow dung	100% Tr. Paper mill sludge
1.	Week I	6820	6080	7135	6620	7251
2.	Week II	9120	9738	9535	9470	8527
3.	Week III	8620	10318	10710	11015	9349
4.	Week IV	10830	10496	12770	12295	10649
5.	Week V	9520	9178	8930	8905	8327
6.	Week VI	9105	9756	8300	7745	8731
7.	Week VII	9095	9658	9470	10275	8987
8.	Week VIII	11980	11486	11560	13015	10249
Total		75090	76710	78410	79340	72070
Weekly average		9386.25	9588.75	9801.75	9917.5	9008.75

Table.7 Effect of pretreated paper mill sludge and cattle dung in various combination on biochemical composition of biogas slurry – field experiments

S. No.	Treatments		pH	VFA mg/litre as acetic acid	Total Solids %	Volatile solids %	Organic Carbon %	Nitrogen %	Phosphorus %	Potassium %	Sodium %	Gas output litre/kg DM
1.	Control	Inlet	7.38	242	10.68	70.30	30.10	2.40	0.191	0.29	3.19	209
		Outlet	7.27	694	7.80	52.80	26.85	3.15	0.615	0.20	0.67	
	75% PMS + 25% cow dung	Inlet	7.20	276	9.89	74.48	29.20	1.61	0.265	0.37	0.70	232
		Outlet	7.06	757	6.92	54.76	25.10	2.59	0.369	0.20	0.63	
2.	Control	Inlet	7.23	221	10.28	63.61	30.40	2.71	0.401	0.08	0.36	216
		Outlet	6.96	716	7.83	58.58	27.90	3.08	0.508	0.05	0.36	
	80% PMS + 20% cow dung	Inlet	7.30	172	10.59	64.52	30.90	2.10	0.376	0.06	0.29	246
		Outlet	7.10	854	6.29	52.48	26.20	2.67	0.348	0.04	0.31	
3.	Control	Inlet	7.23	264	9.96	71.53	29.40	1.49	0.667	0.10	0.50	227
		Outlet	6.87	842	6.38	56.98	26.50	1.86	0.840	0.09	0.38	
	90% PMS + 10% cow dung	Inlet	7.19	248	9.69	61.02	25.20	1.43	0.803	0.11	0.43	252
		Outlet	6.92	954	6.18	50.11	21.40	1.78	0.741	0.08	0.44	
4.	Control	Inlet	7.14	228	10.58	62.65	26.40	1.90	0.072	0.08	0.61	223
		Outlet	6.86	982	7.47	54.02	22.70	2.20	0.061	0.07	0.44	
	100% PMS + 0% cow dung	Inlet	7.21	184	10.05	72.20	27.90	1.86	0.045	0.04	0.71	213
		Outlet	6.91	994	6.97	50.31	22.20	2.04	0.044	0.05	0.49	

Table.8 Effect of chemically treated papermill sludge mixed with cow dung in various proportions on biogas production – field experiments

S. No.	Treatments	Total Solids, %	Gas Production, litre/kg of dry matter	Temperature, °C	
				Min.	Max.
1.	Control	10.68	209	27	32
	75% Tr. Paper mill sludge + 25% cow dung	9.89	232	27	32
2.	Control	10.28	216	28	31
	80% Tr. Paper mill sludge + 20% cow dung	10.59	246	28	31
3.	Control	9.96	227	28	30
	90% Tr. Paper mill sludge + 10% cow dung	9.69	252	28	30
4.	Control	10.58	223	28	30
	100% Tr. Paper mill sludge + 0% cow dung	10.05	213	28	30

Fig.1 Feeding of alkali pretreated Paper Mill Sludge into Biogas plant

Fig.2 Monitoring of biogas production in 2 cu.m pretreated paper mill sludge biogas plant

Fig.3 Gas production per kg of dry matter for various percentage of pretreated paper mill sludge – Lab study

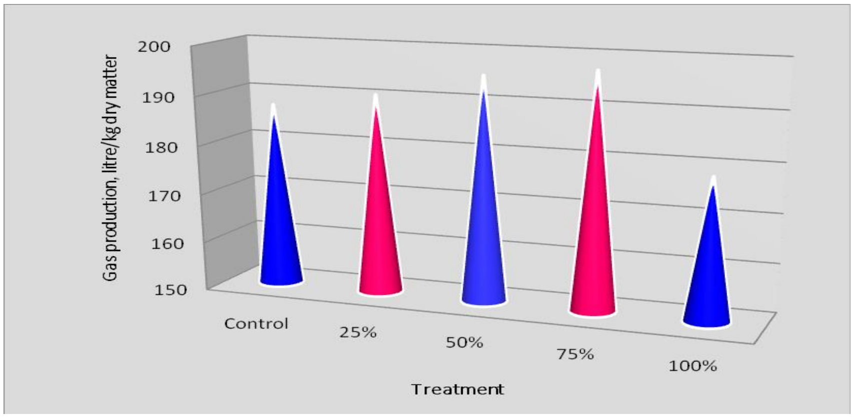


Fig.4 Total gas production for various percentage of pretreated paper mill sludge substitution – Lab study

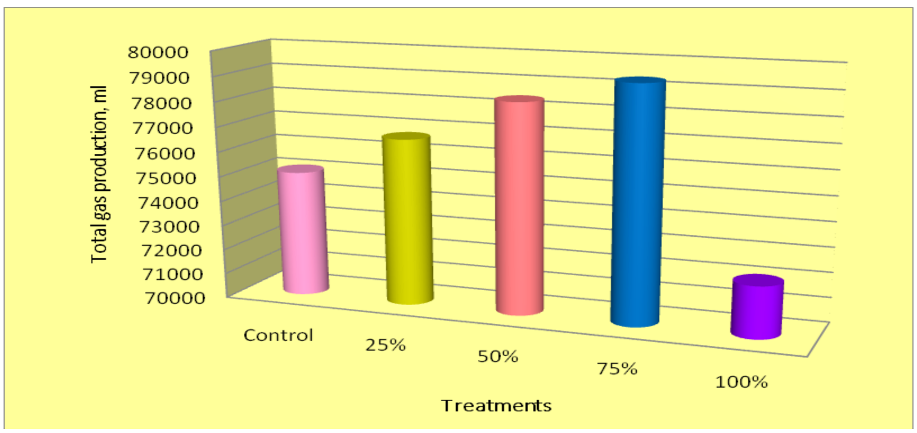


Fig.5 Weekly gas production for various percentage of pretreated paper mill sludge substitution – Lab study

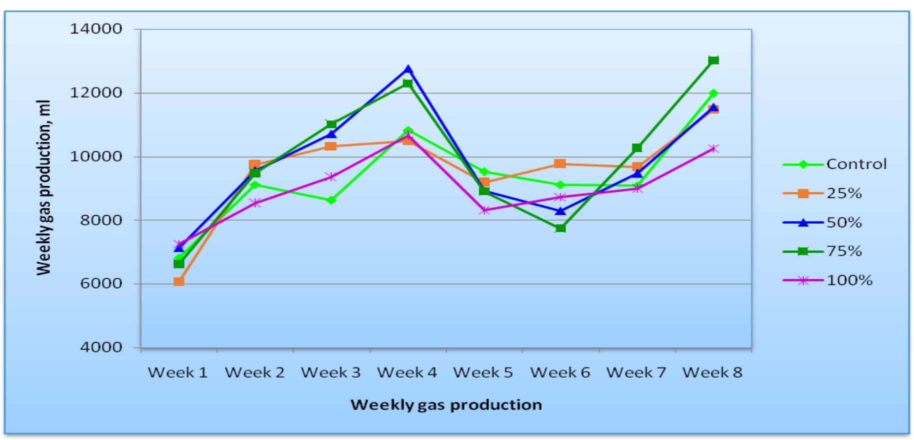


Fig.6 Total gas production for various percentage of pretreated paper mill slugde substitution – Field experiments

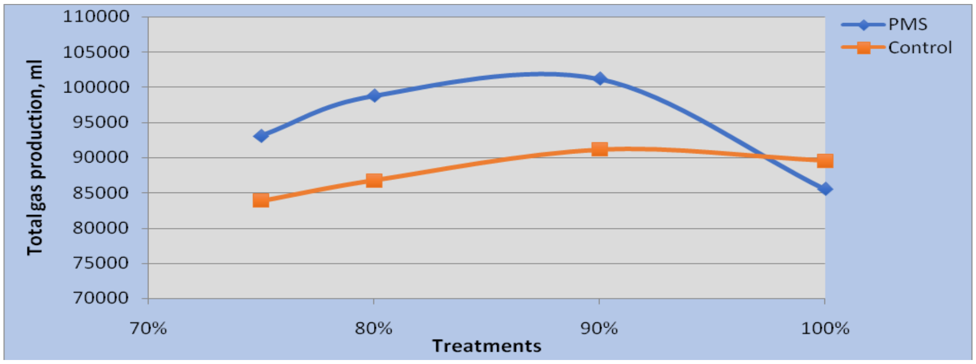
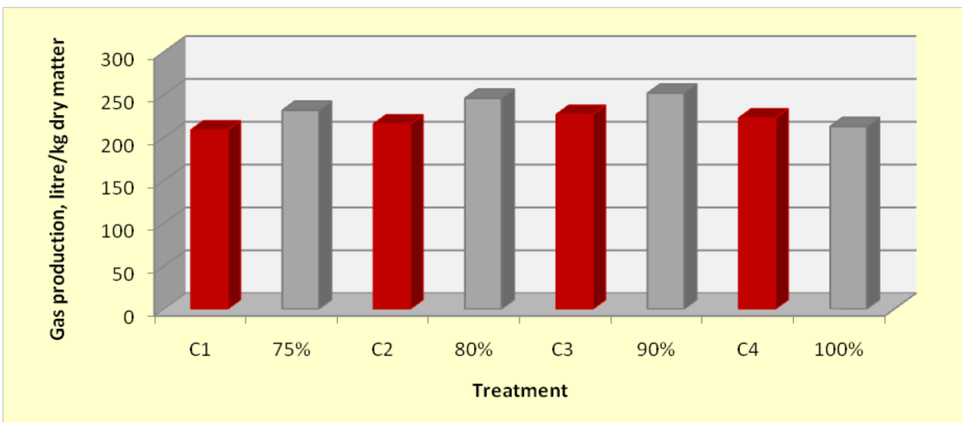


Fig.7 Gas production per kg of dry matter for various percentage of pretreated paper mill sludge – Field experiments



The organic carbon of inlet slurry is much higher than outlet slurry in all treatments, which showed that the carbon content was converted as CO_2 during anaerobic digestion process. The nitrogen content of inlet and outlet slurry of control was higher than the other treatments. In case of phosphorus, potassium and sodium, the outlet slurry has lower value than inlet samples in all treatments except phosphorous.

The digestion period for all the treatments was given as 60 days. Dailybiogas production, total biogas production and weekly biogas production were recorded. The gas production per kg of total solid content was estimated for various treatments of pretreated paper mill sludge substitution and is given in Table 5. The gas production for 25%, 50%, 75% and 100% pretreated paper mill sludge was 190.63 litre/kg of dry matter, 195.44 litre/kg of dry matter, 197.36 litre/kg of dry matter and 178.58 litre/kg of dry matter respectively whereas in control it is 187.54 litre/kg of dry matter. Gas production per kg of dry matter for various percentage of pre treated paper mill sludge in given in Fig. 3. From the figure, the maximum gas production was observed in 75% pretreated paper mill sludge substitution. The weekly gas production for various percentage of pretreated paper mill sludge is given in Table. 6.

The total gas production and weekly gas production throughout the period of anaerobic digestion is given in Figure 4 and 5. It was observed that the minimum and maximum total gas production was 75,090 ml and 79,340 ml respectively. The maximum total gas production was observed in 75% pretreated paper mill sludge substitution. However, there was not much variation from 75% to 100%. It indicates that the paper mill sludge could replace cow dung feeding upto 100% supplementation. Therefore, cattle dung feeding could be completely replaced by pretreated paper mill sludge for biomethanation process.

Based on the laboratory experiments, the alkali pretreated paper mill sludge can be effectively utilized for biogas production upto 75% replacement. It was observed that the minimum and maximum total gas production was 75,090 ml and 79,340 ml respectively. The maximum total gas production was observed in 75% pretreated paper mill sludge substitution. However, there was not much variation from 75% to 100%. It indicates that the paper mill sludge could replace cow dung feeding upto 100% supplementation. Hence, the field experiment was conducted from 75% to 100% substitution of pretreated paper mill sludge.

Field experiments

In field experiments, the biochemical constituents of slurry samples before and after digestion for control and treatment plant is given in Table. 7. The pH of the anaerobic digestion affects the digestive process. The fermentation microorganisms can function in the range of 4 - 8.5 (Hwang *et al.*, 2004). The ideal pH range for anaerobic digestion has been reported as 6.8 - 7.4 (Igoni, 2008). The pH of the slurry samples before and after digestion of each treatment was recorded. The pH of the initial slurry samples was in the range of 7.14 – 7.38 and that of final slurry samples were6.86 - 7.27. In the initial phase of anaerobic digestion process, the production of Volatile fatty acids (VFA) decreases the pH of the slurry. But the reaction of CO_2 which is soluble in water with hydroxide ion forming bicarbonate ions, so forming HCO_3, tends to restore the neutrality of the process pH. When rate of acid formation exceeds the rate of breakdown to methane, the process imbalance which results in pH decrease.

There is a reasonable reduction in total solids and volatile solid content of final slurry samples in all treatments. The total solids of outlet slurry were reduced because of the degradation of solid content during anaerobic digestion. The organic carbon of inlet slurry is much higher than outlet slurry which ranges from 25.20 to 30.90 % in inlet slurry to 21.40 to 27.90 % in outlet slurry of all treatments, which showed that the carbon content was converted as CO_2 during anaerobic digestion process. Similar results were obtained by Lin, Y. Q., 2009. The nitrogen content is higher in outlet slurry samples of both control and treatment plant. The nitrogen content ranges from 1.43-3.15 % of all treatment. In case of phosphorus, the outlet slurry has higher value than inlet samples.

Gas production was also recorded using gas flow meter. Total biogas production, and average biogas production were calculated and recorded. The gas production per kg of total solid content was estimated for various treatments of paper mill sludge substitution in field experiments and is given in Table 8.

The total gas production throughout the period of anaerobic digestion for pretreated paper mill sludge substitution from 75% - 100% and control are given in Fig. 6. The gas production for treatment plant is in the range of 213.0 to 252.0 litre/kg of dry matter whereas in control plant it is 209 – 227 litre/kg of dry matter which is shown in Fig. 7. The gas production was observed to be 232 litre/kg of dry matter for 75% alkali pretreated paper mill sludge, 246 litre/kg of dry matter for 80% alkali pretreated paper mill sludge, 252 litre/kg of dry matter for 90% alkali pretreated paper mill sludge and 213 litre/kg of dry matter for 100% alkali pretreated paper mill sludge.

Hence, the maximum gas production of 252 liter/kg dry matter was recorded in 90% alkali pretreated paper mill sludge substitution whereas in control it was 227 litre/kg of dry matter. Based on the studies conducted earlier for biogas production using untreated paper mill sludge, it was observed that the maximum gas production was recorded in 60% paper mill sludge and it could replace 60% cow dung substitution. Based on this study, it clearly indicates that alkali/NaOH pretreatment enhance the biogas production and effectively utilized the paper mill sludge upto 90% replacement from 60% (Untreated PMS), which shows that alkali pretreatment could be an effective method for improving methane yield in paper mill sludge.

In conclusion based on the laboratory experiments, the alkali pretreated paper mill sludge can be effectively utilized for biogas production up to 75% replacement. However, there was not much variation from 75% to 100%. It indicates that the paper mill sludge could replace cow dung feeding upto 100% supplementation.

To find out the correct proportion of the pretreated paper mill sludge from 75 % - 100%, field experiment was conducted and the maximum gas production was recorded in 90% alkali pretreated paper mill sludge substitution. Based on this study, it clearly indicates that alkali/NaOH pretreatment enhances the biogas production and effectively utilized the paper mill sludge upto 90% replacement.

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