ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Evaluation of performance efficiency of high solid anaerobic digesters of different design with vegetable waste as substrate

S. Venkatesh[1*] and R. Jayashree[2]
[1]Department of Chemistry, Vel Tech High Tech Dr. Rangarajan Dr. Sakunthala Engineering College, Avadi, Chennai, Tamil Nadu, India.
[2]Department of Information Technology, SRM University, Chennai, Tamil Nadu, India.
***Corresponding author: E-Mail: venkat_iomau@hotmail.com**

ABSTRACT

Anaerobic digestion of biodegradable solid wastes is being considered as an effective method of both management of solid wastes and as a renewable source of energy in the form of biogas. Anaerobic digestion is the bacterial fermentation of organic wastes in the absence of free oxygen. Since the vegetable waste forms the major portion of organic waste and generation of biogas seem to be a viable waste management option. The present study focuses, on the anaerobic digestion of vegetable waste using high solid digestion (HSD) of different design. The performance of three types of HSD operated with vegetable waste as substrate was evaluated. The first type digester was with solid and liquid phase within the digester unit. The second type was a single unit without any phase separation. The third type of digester was with a separate solid and liquid phase units. The performance of type III digester was 8.9% higher than type 1 and 23.1% more than type II digester. The highest biogas yield in type III digester was found to be statistically significant at 99% confidential level.

KEY WORDS: Anaerobic digestion, Bio gas production, High solid digestion, Multiphase digestion, Renewable energy, Solid waste management.

1. INTRODUCTION

Anaerobic digestion is bacterial fermentation of organic wastes in the absence of free oxygen. The fermentation when carried out for producing energy, leads to the breakdown of complex biodegradable organics in a four stage process to form an end product called biogas which can be used as fuel or can be converted to electricity with the help of suitable generators (Jagadabhi, 2010; Banks, 2011). Anaerobic process is also found in many naturally occurring anoxic environments including watercourses, sediments, waterlogged soils and the mammalian gut. It can also be applied to a wide range of feedstocks including industrial and municipal waste waters, agricultural, municipal, food industry wastes, and plant residues (Kangle, 2012). Anaerobic process is also found in many naturally occurring anoxic environments including watercourses, sediments, waterlogged soils and the mammalian gut. It can also be applied to a wide range of feedstocks including industrial and municipal waste waters, agricultural, municipal, food industry wastes, and plant residues. The production of biogas through anaerobic digestion offers significant advantages over other forms of waste treatment, including: Less biomass sludge is produced in comparison to aerobic treatment technologies. The production of biogas through anaerobic digestion offers significant advantages over other forms of waste treatment, including: Less biomass sludge is produced in comparison to aerobic treatment technologies. Three physiological groups of bacteria are involved in the anaerobic conversion of organic materials (Figure 1). The first group of hydrolyzing and fermenting bacteria converts complex organic materials to fatty acids, alcohols, carbon dioxide, ammonia and hydrogen. The second group of acetogenic bacteria converts the product of the first group into hydrogen, carbon dioxide, and acetic acid (Xu, 2011). The third group consists of two physiologically different groups of methane forming bacteria, one converting hydrogen and carbon dioxide to methane and the other forming methane from decarboxylation of acetate (Lin, 2010).

The production of biogas through anaerobic digestion offers significant advantages over other forms of waste treatment, including: Less biomass sludge is produced in comparison to aerobic treatment technologies.

a. Successful in treating wet wastes of less than 40% dry matter
b. More effective pathogen removal
c. Minimal odour emissions as 99% of volatile compounds are oxidatively decomposed upon combustion, e.g. H_2S forms SO_2
d. The slurry produced (digestate) is an improved fertiliser in terms of both its availability to plants and its rheology.

Solid wastes constitute a major environmental pollution problem in urban and semi-urban areas of industrially advanced as well as developing countries of the world. The problems like feeding scum formation and clogging encountered during biogasificaton of biodegradable solid, organic wastes in conventional slurry based fermenters have necessitated identifying alternative ways and means of utilizing the solid bio wastes for methane generation (Liu, 2011).

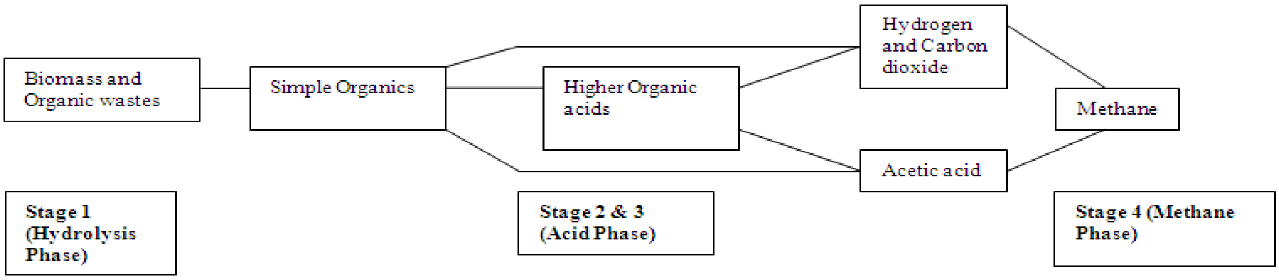

Figure.1.Different phases involved in anaerobic digestion

Anaerobic digestion of biodegradable solid wastes is being as an effective method of both management of solid wastes and as a renewable source of energy in the form of biogas (Charles, 2012). In India, the main problematic solid wastes, besides MSW originate from food processing industries, agro-industrial and agricultural residues. Balasubramaniya (1986) reported the successful biogas generation from willow dust and water mixture in the ratio 1:6 using a laboratory scale plug flow reactor. Shyam and Sharma (1994) reported anaerobic fermentation of agro residues in combination with cow dung using batch reactors. However the gas yield per kg total solids was significantly lower in high solid fermentation (batch type) than form a semi continuous type conventional digester. Anand (1991) applied dry digestion technique suitable to leafy biomass and designed a simple high solid digester with two reservoirs, one packed bed chamber and one solid phase chamber. The aqueous suspension of bacterial consortium was held in the top reservoir, and the same is allowed to sprinkle through over the bed of biomass in the solid phase reactor through the manually operated flow control. It was observed that decomposition of leafy biomass and water hyacinth substrates was rapid taking 45 and 30 days for production of 250 and 235 litres of biogas per kg total solids respectively. Further developments have occurred in similar fashion as in high rate anaerobic digesters, leading to the mixed type high solid digesters. The initial mixed type digesters were called biofunnel which accommodated 13-21% solids (Goldberg, 1981). One approach which holds great promise in solving the technical problems associated with the anaerobic digestion is phase separation or multi-stage digestion. The concept of phase separation involves operating the anaerobic digestion process in distinct phases. This is also termed as three phase or triphasic process. In some cases the first and the second phase are operated together while the methane phase is run separately, such processes are called two-stage or diphasic process. The most notable aspect of multiphase process is its overall speed. For example, in conventional digester it takes 15-20 days for 60-70% conversion of biomass into methane, in multi phase digestion the same result is achieved in less than half of this time, since hydraulic retention has direct bearing on the digester size and consequently on the process economics (Ghosh, 1984). The reduction in conversion time in multi phase digestion leads to a cost advantage. This is also most suitable and efficient process for phytomass digestion.

Rapid urbanization all over the world has created a serious problem of solid waste disposal (Li, 2011). Large vegetable and fruit markets in big cities particularly in the developing countries contribute to the accumulation of this waste which is conventionally disposed by composting, spreading on the land or as animal feed. As the vegetable waste forms the major portion of the organic fraction of MSW, anaerobic fermentation of vegetable wastes seems to be a viable waste management option. Hence our present study focuses on the anaerobic digestion of vegetable waste using high solid digestion (HSD) of different design.

2. MATERIALS

2.1. Vegetable waste: The vegetable waste was chopped manually using knife to approximately 2-3 cm pieces for charging the digesters. The uniformly chopped vegetable waste were analyzed for total solids, volatile solids, moisture content, carbon and nitrogen (APHA, 2005) (Table 1).

Table.1.Characteristics of vegetable waste

Parameters	Results
Total solids	7.93%
Volatile solids	6.74%
Moisture content	92.07%
Nitrogen	336 mg/Kg dry wt.
Carbon	0.506%

2.2. Inocula: In high solid digesters, the effluent slurry form a natural biogas digester was used as inocula. The slurry was mixed with double distilled water (1:4 ratio), stirred well, allowed to settle for about four hours, decanted and filtered through cloth. These inocula were used to feed the digesters (Budiyono, 2010). The inocula were analyzed for total solids, volatile solids, COD (APHA, 2005) (Table 2).

Table.2.Chemical analysis of inocula

Inocula	Total Solids	Volatile Solids	C.O.D.
Digested Cow dung slurry	4700 mg/L	3600 mg/L	11200 mg/L

2.3. Reactors: Digester with phase separation within the single unit. Two laboratory scale digesters of each type (volume -1.1 litres) were fabricated using 2 inch diameter PVC pipe (Figure 2). Each digester unit was divided into two chambers using PVC perforated disc of 6mm diameter. The perforations were made for the movement of the leacheate from the solid bed to the liquid phase during recycling process. The upper chamber was used as solid phase and the lower portion was used as liquid phase. The volume of solid phase compartment was 800 ml, while the volume of the liquid phase chamber was kept as 300 ml respectively. The biogas production from solid phase and liquid phase chambers were measured individually. All the digesters were sealed airtight to prevent the escape of gas.

Digestion without any phase separation: Unlike the above kind of HSDs there was no compartmentalization in the reactor unit (Figure 3). Digestion with separate solid and liquid phase unit: In this type, the volume of solid phase compartment was 800 ml, while the volume of the liquid phase chamber was kept as 300 ml respectively. Both the units were connected by a rubber tube with flow regulator valve (Figure 4).

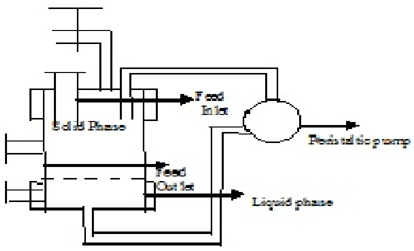

Figure.2.Digester with phase separation within the single unit

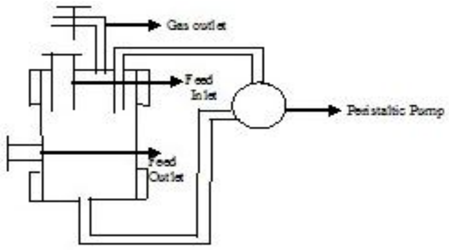

Figure.3.Digestion without any phase separation

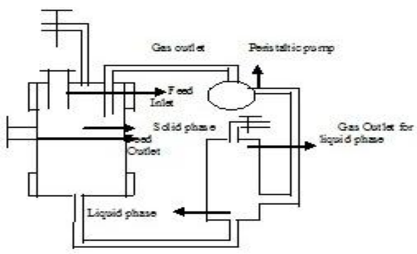

Figure.4.Digestion with separate solid and liquid phase unit

2.4. Digester Operation: Uniformity in operational parameters such as loading rate, temperature, recycling of bioleacheate was maintained in all the digester types. The digesters were charged initially with 25 g of spent material and 6.3 g fresh weight of freshly chopped vegetable waste (0.5 g dry weight). The digesters were fed subsequently with 6.3 g (fresh weight), once weekly for first three weeks prior to start. After 3 weeks, the digester was charged with 50.8 g (fresh weight) and left for acclimation for the next 21 days. On the 21st day they were fed with 100.8 g (fresh weight) once weekly which was continued throughout the period of study. The digested cow dung slurry (250 ml) was used as inoculum. The bioleacheate was circulated over the solid bed in all the types of digesters using peristaltic pump for 20 minutes twice daily at constant flow rates. The liquid was sprinkled with the help of glass sprayer with four arms for spraying. The digester was operated in a batch mode. Once the digester was filled up the n the digested phytomass equivalent to one third volume of the reactor was removed from the bottom portion of the digester. The single feed outlet was provided at the side to remove the digested waste. All the digesters were connected to a gas collecting system with rubber tubing. The gas produced was measured by the graduated plastic cylinders. The gas produced was measured twice a day at twelve hour interval. The gas collecting system was filled with acidified water (pH- 2) in order to prevent the absorption of CO_2 and H_2S from the biogas.

3. RESULTS

The results of the digester performance in terms of biogas yield are given in Table 3. Initially, during the startup period there was a steady rise in biogas yield in irregular fashion in all the digesters (1056-1606 L kg^{-1} VS d^{-1}) from 2nd to 7th week of operation (Figure 5). This increase in gas production rates may be mainly due to favorable temperature and production of CO_2 during the initial stages of operation. Also during the initial periods the population of acidogens is expected to be higher in proportion than the methanogens favouring CO_2 production (Yusuf, 2011). Secondly during the initial periods the availability of empty head space filled with air and the air trapped in between the feed material might encourage the growth of the facultative fermenting and acetogenic bacteria other than methanogens results in high production of CO_2 (Lin, 2010; Chandra, 2012). However the gas yield decreased during the 8th week and steadily increased from 9th week onwards in all the digesters (figure 5). The digesters from the 8th week were fed with 100.8 g fresh weight once in every week throughout the period of study. There was a slight drip in biogas yield on the 13th week in all the three digester types due to the partial removal of the digester contents from the digester unit.

Table.3.Performance of different high solid digester with vegetable waste as feed

Period (Days)	Fresh wt. ($g\ d^{-1}$)	Loading rate ($g\ d^{-1}$)		Type I digester Biogas yield* ($L\ Kg^{-1}\ VS\ d^{-1}$)			Type II digester	Type III digester Biogas yield ($L\ Kg^{-1}\ VS\ d^{-1}$)		
		Total Solids	Volatile Solids	Solid phase	Liquid phase	Total	Total gas yield	Solid phase	Liquid phase	Total
1-7	4.47	0.35	0.29	224.13	210.34	434.47	431.03	245.1	220.34	465.44
8-14	0.9	0.071	0.06	750	666.66	1416.66	1250	767	684.6	1452.66
15-21	0.9	0.071	0.06	833.3	683.33	1516.63	1183	840	697.65	1537.65
22-28	0.9	0.071	0.06	850	716.66	1566.66	1316.6	867	740.66	1607.66
29-35	2.4	0.19	0.16	687.5	593.75	1281.25	1031.2	717	615.05	1332.05
36-42	2.4	0.19	0.16	781.25	687.5	1468.75	1231.25	797	699.5	1496.5
43-49	2.4	0.19	0.16	818.75	756.25	1575	1281.25	829.75	777.2	1606.95
50-56	14.4	1.142	0.97	345.36	335.05	680.41	500	361.85	351.54	713.39
57-63	14.4	1.142	0.97	376.28	365.97	742.25	513	396.9	376.28	773.18
64-70	14.4	1.142	0.97	400	382.47	782.47	561.8	409.27	391.75	801.02
71-77	14.4	1.142	0.97	403.09	387.62	790.71	585.56	411.34	402.06	813.4
78-84	14.4	1.142	0.97	415.46	396.9	812.36	617.52	448.45	423.71	872.16
85-91	14.4	1.142	0.97	409.71	388.65	798.36	622.26	434.02	422.68	856.7
92-99	14.4	1.142	0.97	423.71	407.21	830.92	685.56	479.39	448.98	927.83
100- 105	14.4	1.142	0.97	441.23	413.4	854.63	680.41	484.53	453.6	938.13

***The biogas yield is presented as average of seven days**

The digester without phase separation was found to perform with lowest efficiency in terms of biogas yield (Figure 3). This could be due the fact that both acidogens and methanogens grow in a consortium within the single unit (Chandra, 2012). As the concept of phase separation clearly indicates that both acidogens and methanogens vary in their requirements –namely pH, type of feed, temperature etc. The methanogens are very sensitive to the above mentioned factors while the acidogens are hardier (Abbasi and Ramasamy, 1997) The growth rate of acidogens may be higher while that of the methanogens may be poorer in a single digester unit without any phase separation resulting in poor biogas yield than digester with phase separation (Figure 3). This is further evident from the fact that digester with phase separation within the single digester unit (Figure 2) performed better than digester without phase separation (Figure 3) while the digester with separate solid and liquid phase (Figure 4) performed better than all the digester type in terms of biogas yield. The performance of type III digester was 8.9% higher than type 1 and 23.1% more than type II digester. Therefore separating the solid and liquid phase in a high solid digester does improve the performance of the digester in terms of biogas yield. The phase separation perhaps helps in providing optimal conditions for the respective bacterial groups thereby enhancing their growth and activity. Moreover, by separating the phases as separate entities or units (Figure 4), the flow rate, concentration of volatile fatty acid (VFA) in the bioleacheate can be controlled in order to facilitate the growth of methanogens. Additionally by providing inert support media or by stirring the contents of the liquid phase the activity of methanogens in the liquid phase can be enhanced which in turn increase the biogas yield (De Baere, 2004). The concept of phase separation was clearly stressed in our studies as both acidogens and methanogens vary in their requirements – namely pH, type of feed, temperature etc. The methanogens are very sensitive to the above mentioned factors while the acidogens are hardier (Abbasi, and Ramasamy, 1997). Therefore separating the solid and liquid phase in a high solid digester does improve the performance of the digester in terms of biogas yield because the growth rate of acidogens may be higher while that of the methanogens may be poorer in a single digester unit without any phase separation and may result in poor biogas yield . The another advantage of phase separation is that the liquid effluent would be lesser in VFA content and when recycled into the solid phase using peristaltic pump will not alter the VFA content of the solid phase digester. Hence the pH level within the solid phase digester unit will be quite stable. The stable pH or less altered ph is quite advantageous for the facultative anaerobes and acidogens present in the digester to perform well in terms of biogas yield.

The statistically significant data of biogas yield were assessed by using students –t-test for all the three types of digesters. The digester with separate solid and liquid phase was found to be performing better than all the other types of digester (Table 4).The highest biogas yield was found to be statistically significant at 99% confidence level.

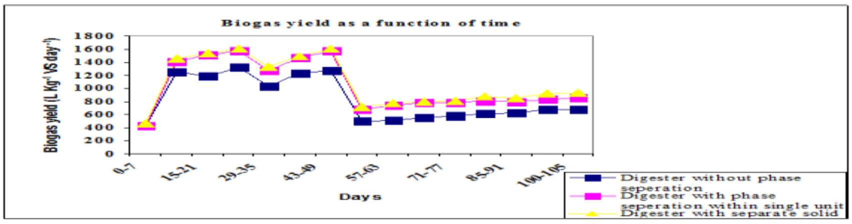

Figure.5.Biogas yield from high solid digester as a function of time

Table.4.Comparison of HSD's in terms of biogas yield

Loading rate (g d^{-1})	Days	Biogas yield (L Kg^{-1} VS d^{-1})		t value	S*/NS**
0.97	20	Type I- 860.12	Type II- 679.19	80.78	S
0.97	20	Type I- 860.12	Type III- 937.72	-39.08	S
0.97	20	Type II- 679.19	Type III- 937.72	-104.33	S

The removed spent phytomass from the digester were analyzed for organic nitrogen (APHA, 2005). The organic nitrogen was found to be 25% more than that of the organic nitrogen content originally present in the feed (Figure 6). The increase in the organic nitrogen can be attributed to the microbial action and the digested material has good fertilizer value. The spent feed with high organic nitrogen content thus can be further used as fertilizer (Zhang, 2010).

4. CONCLUSION

The biogas is composition is of 48–65% methane, 36–41% carbon dioxide, up to 17% nitrogen, <1% oxygen, 32–169 ppm hydrogen sulphide, and traces of other gases. Both carbon dioxide and methane are potent greenhouse gases and possibly 18% of global warming is thought to be caused by anthropogenically derived methane emissions. Thus by containing the decomposition processes in a sealed environment, potentially damaging methane is prevented from entering the atmosphere, and subsequent burning of the gas will release carbon-neutral carbon dioxide back to the carbon cycle. Hence anaerobic digestion can offer a sustainable means of processing biodegradable municipal waste (BMW), and provides a route by which some of the potential energy inherent in this material can be recovered Thus, our studies on anaerobic digestion of vegetable waste indicate that high solid digestion coupled with the concept of phase separation is the better option –rather viable and efficient option for phytomass treatment.

REFERENCES

Abbasi S.A and Ramasamy E.V, Biotechnological pollution control systems: the technologies most appropriate for the third world countries, University press Ltd., Hyderabad, 1997.

Abbasi S.A and Ramasamy E.V, Utilization of biowaste solids by extracting volatile fatty acids with subsequent conversion to methane and manure, In: Proceeding of the twelfth International Conference on Solid waste Technology and Management, Philadelphia, USA, 1996.

Abbasi S.A, and Nipaney P.C, Modelling and simulation of biogas systems economics, Ashis Publishers, New Delhi, 1993.

Abbasi S.A, Nipaney P.C, and Ramasamy E.V, Studies on multiphase anaerobic digestion of Salvinia, Indian Journal of Technology, 30, 1992, 483-490.

Anand V, Chanakya H.N, and Rajan M.G.C, Solid phase fermentation of leaf biomass to biogas, Resource conservation and recycling, 6, 1991, 23-33.

APHA, Standard Methods for the Examination of Water and Wastewater, 21st edition, American Public Health Association, American Water Works Association, Water Environment Federation, 2005.

Balasubramaniya R.H, Khadeparkar V.G, Betrabet S.M, and Sudaram V, Production of biogas from willow-dust by a batch fermentation process, Journal of textile association, 42, 1991, 145-149.

Balch W.E, Fox G.E, Magrum L.J, Woese C.R, and Wolfe R.S, Methanogenesis reevaluation of a unique biological group, Microbiological review, 43, 1979, 260-296.

Banks C.J, Chesshire M, Heaven S, and Arnold R, Anaerobic digestion of source-segregated domestic food waste: performance assessment by mass and energy balance, Bioresource Technology, 102(2), 2011, 612-620.

Bryant M.P, Wolin M.J, and Woife R.S, Methanobacillus omlianskii, A symbiotic association of two species of bacteria, Achieves Microbiology, 59, 1967, 20-31.

Budiyono, Widiasa I.N, Johari S, and Sunarso, The kinetics of Biogas Production Rate from cattle manure in Batch mode, International Journal of chemical and Biomolecular Engineering, 3, 2010, 39-44.

Chanakya H.N, Sushma Borgaonkar, Meena G, and Jagadish K.S, Solid phase biogas production with garbage or water hyacinth, Bioresource Technology, 46, 1993, 227-231.

Chandra R, Takeuchi H, & Hasegawa T, Methane production from lignocellulosic agricultural crop wastes: A review of second generation of biofuel production, Renewable and Sustainable Energy Reviews, 16, 2012, 1462-1476.

De Baere L, The role of anaerobic digestion in the treatment of MSW: state of the art, In preprints of IWA Conference Anaerobic Digestion, AD 10th, Montreal, Canada, 2004, 395–400.

Ghosh S, Solid phase digestion of low moisture feeds, Biotechnology Bioengineering Supplement, 14, 1984, 365-376.

Hansson G, Methane production and product inhibition, thermophilic methane fermentation and production of methane from algae, PhD thesis, Department of Technical Microbiology, University of Lurd, 1981.

Jagadabhi P.S, Kaparaju P, and Rintala J, Effect of micro-aeration and leachate replacement on COD solubilization and VFA production during mono-digestion of grass-silage in one-stage leach-bed reactors, Bioresource Technology, 101, 2010, 2818-2824.

Kangle K.M, Kore S.V, and Kulkarni G. S, Recent Trends in Anaerobic Codigestion: A Review. .Universal Journal of Environmental Research and Technology, 2(4), 2012, 210-219.

Li Y, Park S.Y, & Zhu J, Solid-state anaerobic digesters for methane production from organic waste, Renewable and Sustainable Energy Reviews, 15, 2011, 821-826.

Lin Y.Q, Wang D.H, and Wang L.S, Biological pretreatment enhances biogas production in the anaerobic digestion of pulp and paper sludge, Waste Management & Research, 29, 2010, 1-11.

Liu Y, Zhu B, Zou D, Fang G, Mao J, Li X, Performance of vegetable wastes anaerobic digestion at different inoculums and organic loads, Proceedings of the International Conference on Solid Waste 2011- Moving Towards Sustainable Resource Management, Hong Kong SAR, P.R.China, 2011.

Mah R.A, Ward D.M, Baresi L, and Glass T.L, Biogenesis of methane, Annuals Reviews Microbiology, 31, 1977, 309-334.

Mosey F.E, Mathematical modelling of the anaerobic digestion process regulatory mechanism for the formation of short chain volatile fatty acids from organic glucose, Water Science and Technology, 15, 1983, 209-232.

Nagar B.R, and Tietjan C, A status report on the use of biogas technology for increasing fuel and soil productivity, Journal of Scientific and Industrial Research, 37, 1978, 445-448.

Shasikant R.M, and Abande K.U, Anaerobic digestion of vegetable solid waste as a method of solid waste management, Institution of Public Health Engineers, 1, 1995, 92-99.

Shyam M, and Sharma P.K, Solid-state anaerobic digestion of cattle dung and agro-residues in small capacity field digesters, Bioresource Technology, 48, 1994, 203-207.

Yusuf M.O.L, Debora A, & Ogheneruona D.E, Ambient Temperature Kinetic Assessment of Biogas Production from co-igestion of Horse and Cow Dung, Res.Agr.Engineering, 57(3), 2011, 97-104.

Zhang L, Jiang Y, Deng Z, Feasibility analysis of treating and recycling municipal biomass waste using anaerobic digestion, Environmental Science and Technology, 33, 2010, 143-146.