Journal of Environmental Biology **October 2007,** 28(4) 741-745 (2007)

Solid state biomethanation of fruit wastes

J. Rajesh Banu[3], Essaki Raj[1], S. Kaliappan[1], Dieter Beck[2] and Ick-Tae Yeom*[1]
*yeom@skku.ac.kr

[1]Centre for Environmental Studies, Anna University, Chennai-600 025, India
[2]Indo German Project, Centre for Environmental Studies, Anna University, Chennai-600 025
[3]Civil and Environmental Engineering, Center for Zero Emission Technology, Sungkyunkwan University, Chunchun-dongJangan-gu-440-746 Suwon-Si, Korea

(Received: November 19, 2005 ; Revised received: April 22, 2006 ; Accepted: June 06, 2006)

Abstract: *Over tones of fruit wastes accumulate daily in the city of Chennai, India and there is an urgent need to develop, assess and use ecofriendly methods to dispose them. Presently, an attempt has been made to study solid state biomethanation of fruit wastes using a laboratory scale anaerobic digester. Fruit wastes containing 3%, 4% and 5% solids were used for experimentation. Daily and cumulative production of biogas produced during the study was recorded. Increase in nitrogen, phosphorus and potassium content in the feed was observed during the digestion. During the study, the biogas generation increased with increase in total solids. While the gas generation was 0.006 m^3/day/m^3 of the reactor volume when the solid content was 3% the corresponding values for 4% and 5% solids were 0.27 and 0.35 m^3 respectively. Varying TS 3% to 4% has no effect on fermentation stability and pH remained between 6.8 and 7.4, but an inhibition of methanogenic bacteria was observed for TS 5%. The overall performance of the reactor was depressed by changing feed concentration from 3% to 5%. Experiments with 4% initial solid contend was ideal for solid-state biomethanation.*

Key words: *Biomethanation, Fruit wastes, Total solid, Biogas composition*
PDF file of full length paper is available with author

Introduction

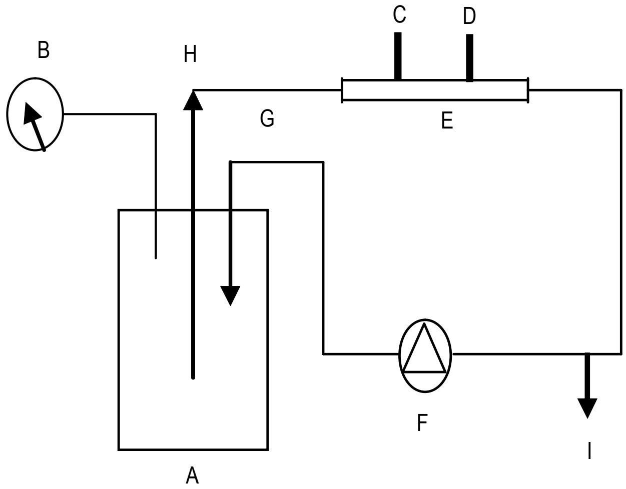
The annual production of fruits in India is estimated to be over 60 x 10^6 tones. During their transport from the harvesting place to the marketing centers, a sizable portion is lost due to poor and inadequate transport, storage facilities and marketing practices. This portion is estimated to be about 40% of the produce and is valued at Rs. 30,000 million (Mital, 1996). Only 0.5% of these wastes are converted into various products (Vimal and Adsule, 1976). The balance is disposed off in many ways, which create pollution problems besides causing nuisance. In recent years, attention is being given to treating the wastes chemically or biologically to obtain useful by products before the final disposal. Of the many alternatives, anaerobic treatment of fruit wastes to generate biogas has been attracting the attention of researchers. There are reports on anaerobic treatment of food processing wastes (Wang *et al.*, 2002; Rajesh Banu *et al.*, 2007), wastes of human origin (Khandelwal and Mahdi, 1989), wastes of animal origin (Shihwu and Santha, 2003; Sanchez *et al.*, 2003), by products and wastes from agriculture based industries (Chen, 1983; Rajesh Banu *et al.*, 2006; Singh, 2007), wastes from aquatic growth (Chynoweth *et al.*, 1987). While reports on biomethanation of parts of fruits such as peels are available (Srilatha *et al.*, 1995), studies to tackle the composite wastes collected at market yards appear to be wanting. The present study is an attempt in this direction.

Materials and Methods

Fruit wastes for the present study were collected from the corridors of Koyambedu wholesale fruit market in Chennai, India. The wastes were hand picked and utmost care was taken to include all varieties of fruits. The wastes were transported to laboratory in polyethylene bags and stored at 4°C as recommended in Kostenberg and Marchaim (1993). The wastes were segregated into different fruit types (Table 1). The moisture content of each type was determined using moisture balance (Make: Sartorius, Model No: MA 30). A raw mixture of fruit wastes was prepared by pooling 700 g of each type. The mixture was grounded into a soft paste using a hand mixer. The paste was sieved through a 1 mm filter and the filtrate was stored in a stainless steel container at 4°C. This filtered material was used as “feed” for all further studies.

The feed was analysed for determining total solids (TS), volatile solids (VS), chemical oxygen demand (COD), Total kjeldahal nitrogen (TKN), phosphorus and potassium, employing methods detailed in standard methods (APHA, 1998). The feed undergoing digestion was also analysed for the same parameters, once in five days, for each TS loading. Potassium was determined using a flame photometer (Make: Chemito, Model No: Chemito-1000). The composition of biogas was analysed using a gas chromatograph (Make: chemito, Model: GC 1000) with porapak Q column.

Fabrication and setting up of anaerobic digester: The construction details of the laboratory scale digester used for the study are shown in Fig. 1. A round bottom glass container of five-liter capacity (Borosil make) was used as the digester. The mouth of the reactor was closed with a lid having three openings. Through one of the openings a glass tube was inserted to reach the bottom of the reactor. This served as the outlet for digested waste. Another tube inserted through the second opening served as the inlet for the feed. To facilitate the circulation of feed, a common tube was used to



A = Digester B = Wet gas meter F = pH probe
D = Digital thermometer E = Connecting tube F = Peristaltic pump
G = Sample inlet H = Sample outlet I = Sampling tube

Fig. 1: Laboratory scale digester

connect the outlet and inlet tubes. In the connecting tube provisions were made to place pH (Make: Elico, Model: LI 120) and temperature probes (Make : Amadigit, Model: ad 20). A peristaltic pump was used for circulating the feed. The third opening served as the outlet for gas. Through this a tube was connected to a wet gas meter (Make: Ritter, Model: TG 05). The entire experimental unit was made airtight by applying a chemical sealing agent (M-Seal manufactured by Mahindra and Mahindra Company, Pune, India).

Start up: As fruit wastes lack population of anaerobic bacteria required for the digestion, an innoculum was used and the procedure formulated by Nand *et al.* (1991) for a semi continuous reactor was adopted for the start up phase of the experiment.

Digested slurry collected from an active biogas plant located at Murugappa Chettiar Research Center, Chennai, India was used as the inoculum. Composite fruit waste filtrate and the slurry were mixed in (20:80) and placed in the reactor. The ratio was increased to 40:60, 60:40 and 80:20 at weekly intervals. At the end of the fifth week unmixed composite fruit waste filtrate was used as a feed. The waste filtrate was appropriately diluted using dilution water so as to obtain the "test feed" containing different concentration of TS. Test feeds with 3, 4 and 5% TS were used for biomethanation lasting for 20-25 days. Throughout the study period the pH of the feed was maintained within the acceptable range of 6.8 to 7.2 (Van Haandel and Lettinga, 1994). The feed temperature during the study was in the range of 29.8 to 37.6°C, which is recommended for efficient mesophilic anaerobic digestion (Bhatti *et al.*, 1996).

Results and Discussion

Table 1 presents data on the moisture, TS, VS and ash content of the fruit waste. From the table it is evident that the grape had maximum moisture content of 92.1% and banana the least (68.5%). The maximum TS content was recorded in banana (31.1%). The VS in fruits used for the study varied from 98.2 (grape) to 99.9% (banana). The present results for individual fruit types are comparable to values reported by Mital (1996). Viswanath *et al.* (1992) have reported that banana and tomato contain 29.5 and 11.8% solids, respectively. These are also comparable to values recorded presently. Working on food processing wastes including peels of mango, tomato, lemon, orange and pineapple, Nand (1994), has reported that the solid content in them varied from 28.40 to 23.40%. The values for VS obtained presently are comparable to 92.73% reported by Nand (1994) for rotten fruits and vegetable wastes. The variation in the values could be attributed to the nature of the waste mix. The presence of high moisture content in the fruit waste facilitates the anaerobic digestion (Bouallagui *et al.*, 2003).

Table 2 presents a profile of TS, VS and COD of fruit waste during biomethanation. The solid content in the feed decreased gradually as the digestion period increased. The feed containing 3, 4 and 5% TS exhibited a reduction of 48-56% (computed from data in Table 2). The VS in the feed material too decreased as the digestion period increased. Reduction of 62, 60 and 53% VS was observed in test feed containing 3,4 and 5% TS, respectively. Similar to present study (Mital, 1996) has reported a VS reduction ranging from 72 to 64% during the anaerobic fermentation of tomato wastes. Bouallagui *et al.* (2003) in his experiment with fruit and vegetable waste in tubular reactor observed a VS reduction of 59 to 74%. COD destruction was higher in the feed material containing 3% TS as compared to that containing 4 and 5%, the corresponding values being 70, 69 and 62%. The pattern for COD destruction observed presently is similar to that reported by Mital (1996) for tomato waste.

The relationship between daily gas yield and pH during the 20 day digestion period for TS 3% is depicted in Figure 2. In the experiment with an initial TS of 3%, the gas production commenced on the first day onwards. The maximum gas production was recorded on 5th day. From then on there was a gradual decrease in daily gas yield and the gas production was very less towards the end (50 ml). During the 20th day digestion period the pH was in the range of 6.8 to 7.4 and it indicates that the reactor was running in a healthy condition, as pH with in the range 6.8 to 8.2 was a good indicator of healthy reactor performance (Wheatley, 1991).

Table - 1: Composition of fruit waste

Name of fruit	Weight (g)	Moisture (g)	Total (%)	Volatile solids (%)	Ash solids (%)
Apple	700	82.0	18.0	99.8	0.2
Orange	700	85.2	14.8	99.7	0.3
Pineapple	700	80.1	19.9	99.8	0.2
Sapota	700	78.0	21.1	99.5	0.5
Grape	700	92.1	7.9	98.2	1.8
Mango	700	74.2	25.8	99.7	0.3
Banana	700	68.5	31.5	99.9	0.1

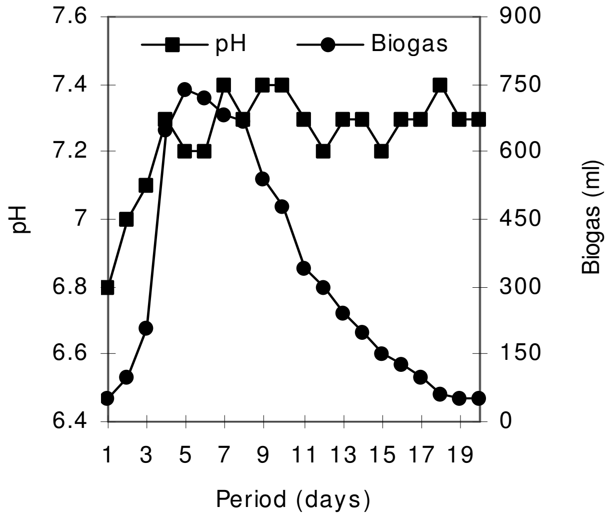


Fig. 2: Relationship between pH and biogas production during biomethanation of fruit waste with TS 3%

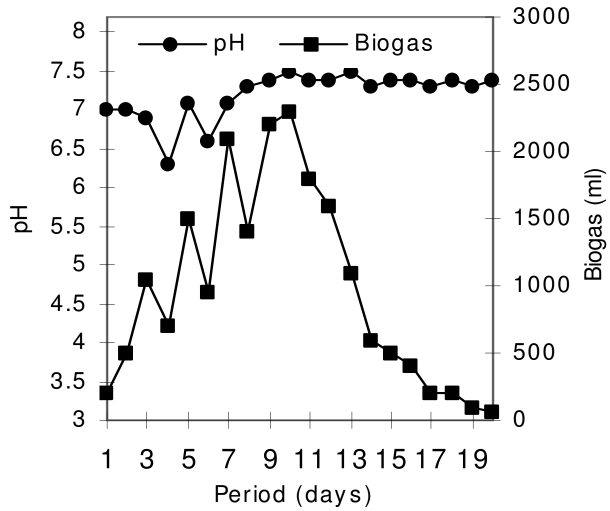


Fig. 3: Relationship between pH and biogas production during biomethanation of fruit waste with TS 4%

Table - 2: Presents profile of TS, VS and COD of fruit waste during biomethanation

Phase	Digestion period (days)	TS 3%			TS 4%			TS 5%		
		TS (%)	VS (%)	COD (mg/l)	TS (%)	VS (%)	COD (mg/l)	TS(%) (%)	VS(%) (%)	COD (mg/l)
1	0	3.0	62	20,080	4.0	80	29,616	5.0	91	38,100
2	5	2.7	54	17,276	3.6	70	24,540	4.4	85	32,540
3	10	2.1	39	12,660	2.8	54	17,856	3.6	70	24,052
4	15	1.6	29	9590	2.2	40	13,050	2.9	55	19,054
5	20	1.3	23	6850	1.8	32	9,080	2.6	42	15,104

Fig. 3 depicts the profile of daily biogas production and pH during biomethanation of fruit waste with initial TS 4%. The gas production commenced on the 1st day and exhibited an increasing trend upto 11th day. The maximum gas generation was recorded on 10th and 11th days. Marked dip in gas production was observed on 4th and 6th days. The corresponding pH of the feed on those days was 6.3 and 6.6. The pH of the feed was adjusted to 7.2 using 1N NaOH on those days and the gas yield increased subsequently. After 13th day the generation of gas decreased gradually.

The relationship between biogas production and pH in the experiment with initial TS of 5% is shown in the Fig. 4. The gas production started from 1st day and the maximum generation of 2800 ml was recorded on the 11th day. During the 25th day experimental period, pH correction was effected on the 4th, 6th, 8th, 10th and 12th days; corresponding pH of the feed on that day were 5.9, 6.6, 6.1, 6.6 and 6.5. Interestingly, consequent to pH correction the gas yield increased in all cases. This could be attributed to the neutralization of VFA by added alkali. It is known that VFA is potential inhibitor of anaerobic digestion; accumulation of VFA lowers the pH of the reactor that leads to reactor souring (Pind *et al.*, 2002; Pind *et al.*, 1999; Fang *et al.*, 1994).

Table 3 presents the pattern of nutrient mineralization by the microbial population during the study period. In the experiments with 3% and 4% TS, the increase of nitrogen during the 20th day digestion period was 2.24 and 2.37 g/kg TS of the initial nitrogen content 1.06 and 1.19 g/kg TS respectively. The increase was 2.20 g/kg TS from the initial content of 1.25 g/kg TS during the 25th day digestion period in the experiment with 5% TS. From the Table 3 it is evident that the fold in increase of nitrogen was maximum during phase 2 *i.e.*, day 6 to 10 and the fold in increase decreased thereafter during the 20th day digestion period with 3% and 4% TS and 25 day digestion period in the experiment with 5% initial TS. The pattern of mineralization of phosphorus during different phases was similar to that of nitrogen utilization. In case of potassium, the fold in increase was 2.4 when the initial TS was 3%, 2.3 of the initial 4% TS and 2% of 5% initial TS in the feed. The increase in nitrogen and phosphorous content in the feed can be attributed to mineralization of organic compounds containing organic nitrogen and phosphorous (Coombs, 1994). Unlike in the case of nitrogen and phosphorus the potassium utilization indicated a continuous and gradual increase throughout the digestion period. It is interesting to note that the phases of increased

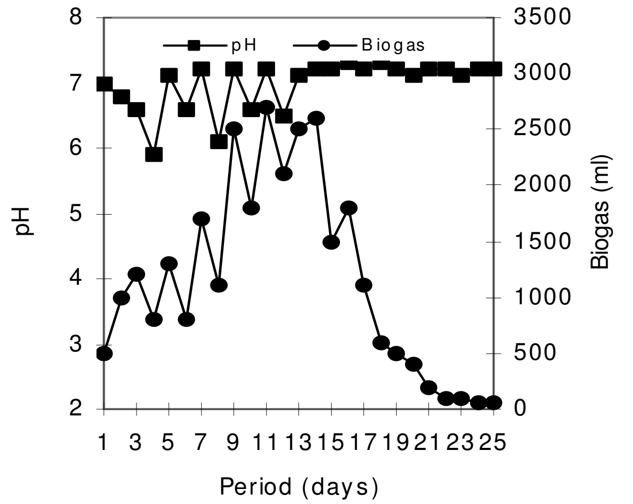


Fig. 4: Relationship between pH and biogas production during biomethanation of fruit waste with TS 5%

utilization of nutrients corresponded with phases of increased generation of biogas. This observation is suggestive of the active metabolic status of microbes and consequent increase in biomass. Similar to our finding, Bouallagui *et al.* (2003) for mixed fruit and vegetable waste and Meher and Gollakota (1994a), for food material have reported increases in nitrogen and phosphorous contents in the feed material during solid-state biomethanation.

Table 4 presents data on the influence of digestion period on generation, productivity profile and composition of biogas. The daily gas generation increased with increases in initial concentration of solids in the feed. An increase of 1% solids in the feed resulted in over 4 fold increase in daily gas generation (0.25 l/day for 3% TS and 1.1 l/day 4% TS). When the initial TS of feed increased from 4 to 5%, the gas generation was 1.4 l/day, amounting to 1.3 fold increase. Similar correlation between increase in solids in the feed and daily gas generation has been reported by Meher and Gollakota (1994b). Productivity of gas expressed in terms of m^3 gas /m^3 gross digester volume and it increased with increases in the solids content of the feed. It is known that values in the range of 0.2 to 0.5 m^3 gas/ m^3 digester volume indicate higher efficiency of biomethanation and the present values fall in this range.

Table - 3: Nutrient mineralization during the biomethanation of fruit wastes

Phase	Digestion period (days)	TS 3%			TS 4%			TS 5%		
		Nitrogen (g/kg TS)	Phosphorus (g/kg TS)	Potassium (g/kg TS)	Nitrogen (g/kg TS)	Phosphorus (g/kg TS)	Potassium (g/kg TS)	Nitrogen (g/kg TS)	Phosphorus (g/kg TS)	Potassium (g/kg TS)
1	0	1.06	0.58	1.50	1.19	0.68	1.65	1.28	0.74	1.95
2	1-5	1.25	0.69	2.08	1.30	0.80	2.19	1.43	0.86	2.28
3	6-10	1.65	0.93	2.65	1.69	1.00	2.87	1.78	1.02	2.78
4	10-15	1.98	1.10	3.17	2.01	1.15	3.43	1.93	1.13	3.21
5	16-20	2.24	1.24	3.60	2.37	1.37	3.82	2.10	1.23	3.69
6	20-25							2.20	1.32	4.01

Table - 4: Productivity profile and composition of gas from fruit waste biomethanation

Phase	Digestion period (days)	Initial solids in the feed (%)	Gross volume of the digester (L)	Working volume of the digester (L)	Daily gas generation (L)	Productivity (m^3gas/m^3) working volume	Productivity (m^3gas/m^3) digester volume	Methane (%)	Carbon dioxide (%)
1	20	3	5	4	0.256	0.04	0.06	60-70	30-40
2	20	4	5	4	1.100	0.20	0.27	63-75	25-37
3	20	5	5	4	1.420	0.28	0.35	63-74	26-37
4	25	5	5	4	0.060	0.01	0.01	-	-

The methane content in the biogas generated from the feed containing 3% TS varied from 60 to 70%. The corresponding values for gas generated from feeds containing 4 and 5% TS were 63 to 75% and 63 to 74%, respectively. The carbon dioxide content varied from 30 to 40% in gas generated from feed containing 3% TS. The corresponding figures for gas generated from feeds containing 4 and 5% TS were 25 to 37% and 26 to 37%, respectively. The present range of values for both methane and carbon dioxide content in the biogas compares well with those obtained during the biomethanation of variety of feed materials (Nand *et al.,* 1991; Shing *et al.*, 2003 and Pain *et al.*, 1984).

From the foregoing, solid-state biomethanation appears to be a viable option for disposing fruit wastes in an eco-friendly manner. Further studies focusing on the microbial dynamics, impacts of environmental factors and engineering aspects such as retention time, organic loading rate and feed recirculation rate would help evaluate the process and its application and pave way for pilot plant experiments. Work on these aspects is in progress.

Acknowledgments

Authors are thankful to Indo-German Project at Centre for Environmental Studies, Anna University, Chennai-25, India for providing the necessary facilitities and Sungkyunkwan University, South Korea for providing the financial assistant to this project. The authors were also thankful to the authorities of the local fruit market for their help in collecting the wastes.

References

APHA.: Standard methods for the examination of water and wastewaters. 20th Edn. Washington, D.C, USA (1998).

Bhatti, Z.I., K. Furukawa and M. Fujita: Flexibility of methanolic waste treatment in UASB reactors. *J. Appl. Environ. Microbiol.,* **80**, 2559-2568 (1996).

Bouallagui, H., H. Ben Cheikh, L. Marouani and M. Hamdi: Mesophilic biogas production from fruit and vegetable waste in tubular digester. *J. Biores. Technol*., **86**, 85-89 (2003).

Chen, Y.R.: Kinetic analysis of anaerobic digestion of pig manure and its design implications. *J. Agric. Wastes*, **8**, 65-81 (1983).

Chynoweth, D.P., K.F. Fannin and V.J. Srivastava: Development in Aquaculture and Fisheries Science. Elsevier Science Publishers, Amsterdam (1987).

Coombs, J.: The present and future of anaerobic digestion anaerobic digestion: A Waste Treatment Technology. Elsevier Science Publishers, London (1994).

Fang, H.H.P., H.K. Chui, Y.Y. Li and T. Chen: Performance and granule characteristics of UASB process treating wastewater with hydrolyzed proteins. *Water Sci. Tech.,* **30**, 65-73 (1994).

Khandelwal, K.C. and Mahdi: Biogas Technology - Volume I. Tata Mc Graw-Hill Publishing Co. Ltd., New Delhi (1989).

Kostenberg, D. and Marchaim: Thermophilic anaerobic treatment of tea waste. *Water Sci. Tech.,* **2**, 99-107 (1993).

Meher, K.K. and K. Gollakota: Alternative feed stock (Tobacco Cake) for biogas production. *Indian J. Environ. Protect*., **9**, 682-684 (1994a).

Meher, K.K. and K. Gollakota: Biomethanation of De-oiled mohawa seed cake. *Indian J. Environ. Protect*., **10**, 737-739 (1994b).

Mital, K.M.: Biogas system principles and Applications. New Age International Private Limited, New Delhi, India (1996).

Nand, Krishna: Biogas from food wastes. *Indian Food Industry*, **3**, 23-24 (1994).

Nand, Krishna, Sumithra Devi, Prema Viswanath, Somayaji Deepak and R. Sarada: Anaerobic digestion of canteen wastes for biogas production, Process optimization. *Proc. Biochem.,* **26**, 1-5 (1991).

Pain, B.F., R. West, B. Oliver and D.L. Hawkes: Mesophilic anaerobic digestion of dairy cow slurry on a farm scale: First comparisons between digestion before and after solids separation. *J. Agric. Eng. Res.,* **29**, 249-256 (1984).

Pind, E.P., I. Angelidaki and B.K. Ahring: The use of VFA measurement as process indicators in anaerobic reactors treating manure. II International symposium on anaerobic digestion of solid waste. Barcelona, Vol. 2. pp. 41-44 (1999).

Pind, E.P., I. Angelidaki and B.K. Ahring: Dynamics of the anaerobic process: Effects of volatile fatty acids. *J. Biotech Bioeng*., **82**, 791-801 (2002).

Rajesh Banu, J., S. Kaliappan, M. Rajkumar and Dieter Beck: Treatment of spent wash in anaerobic mesophilic suspended growth reactor (AMSGR). *J. Environ. Biol.,* **27**, 111-117 (2006).

Rajesh Banu, J., S. Kaliappan and Dieter Beck: Treatment of spent wash in anaerobic thermophilic suspended growth reactor (ATSGR). *J. Environ. Biol.,* **28**, 517-521 (2007).

Sanchez, L., P. Travieso, Weiland, R. Borija and S. Nikolaeva: Effect of influent strength changes on the performance of a down flow pigery waste. *Resources Conservation and Recycling*, **36**, 73-82 (2003).

Shihwu, Sung and Harikrishan Santha: Performance of temperature-phased anaerobic digestion system treating dairy cattle wastes. *J. Water Res*., **36**, 73-82 (2003).

Shing, Tet Leong, Muttarmara and Preechai Laortanakul: Reutilization of wastewater in a rubber-based processing factory: A case study in southern Thailand. *Resources Conservation and Recycling,* **7**, 159-172 (2003).

Singh, Pratibha: Sequential anaerobic and aerobic treatment of pulp and paper mill effluent in pilot scale bioreactor. *J. Environ. Biol*., **28**, 77-82 (2007).

Srilatha, H.R., Krishna Nand, K. Sudhakar Bhau and K. Madhukara: Fungal pretreatment of organic processing waste by solid state fermentation for improved production of methane. *Proc. Biochem.,* **30**, 327-331 (1995).

Van Haandel, C. and G. Lettinga: Anaerobic sewage treatment: A practical guide for regions with a hot climate. Wiley publishers, U.K. (1994).

Vimal, O.P. and P.G. Adsule: Utilisation of fruit and vegetable wastes. *Research Industry,* **21**, 1-6 (1976).

Viswanath, Prema, S. Sumithra Devi and Krishna Nand: Anaerobic digestion of fruit and vegetable processing wastes for biogas production. *Biores. Technol*., **40**, 43-48 (1992).

Wang, J.Y., H.L. Xu and L.H. Tay: A hybrid two phase system for anaerobic digestion of food waste. *Water Sci. Tech.,* **45**, 159-165 (2002).

Wheatley, A.: Anaerobic Digestion: A waste treatment technology for developing countries. Elsevier Science Publisher Ltd., 2nd Edn., U.K. (1991).