World Applied Sciences Journal 9 (8): 950-956, 2010
ISSN 1818-4952

Kinetics and Bioenergy Conversion Studies of Mango Pulp Industry Solid Wastes

S. Anhuradha and P. Mullai

Department of Chemical Engg, Annamalai University, India

Abstract: The objective of this study was to characterise anaerobic batch biomethanation of mango peel waste (MP) and biodigestion with cow-dung (CD). The effects of increasing the concentration of mango peel waste as percentage of total solids (4 to 12) and varying the ratios of CD: MP (1:2, 1:5 and 1:10). A maximum methane yield of 3.5811 CH_4/g VS $_{degraded}$ was obtained at 8% TS and ratio of 1:10. A methane content of up to 65% was obtained at this proportion. Addition of cow dung led to faster onset of biogas production and higher methane productivity. The reductions in volatile solids in the entire BMP test were in the range of 96% to 98%. The specific gas production for mango peel was higher (5.3926 l biogas / g VS in and 5.5093 l biogas / g VS des) for the 1:10 ratio at 8% TS than for the 1:2 ratio 2.0342 l biogas/g VS in and 2.4535 l biogas/g VS des at 4% TS. Consequently, the specific gas production for the mango peel, co-digestion with cow dung for the 1:10 at 8% TS was higher, compared to other values. The organic waste available from the mango peel contains easily biodegradable organic matter and this contributed to a better biogas yield. Batch kinetics of anaerobic digestion is useful in predicting the performance of digesters and for the design of appropriate digesters.

Key words: Anaerobic digestion · Mango peel · Methane yield · Batch kinetics · Digester efficiency

INTRODUCTION

With today's energy demanding life-styles, the need to explore and exploit new energy sources that are renewable and ecologically sound in mandatory. In most developing countries agro industrial residues are available in abundance. Through anaerobic digestion and biogas production, these have great potential in catering for the energy demand, especially in the small-scale or local energy sector. The bio-methane from agro industry waste i.e. mango peel waste, a waste material of the mango pulp industry, is of great interest as a renewable energy carrier that could be used for heat and/or power generation [1]. Anaerobic digestion is a biodegradation process, which uses a consortium of natural bacteria to convert a large portion of the organic waste into Bioenergy. The biogas is mainly a mixture of methane and carbon dioxide and if captured, is a gas fuel used for heat and / or power generation [2].

Fruit and vegetable wastes are highly biodegradable wastes which represent a potential energy resource for producing biogas by biological process [3, 4]. Normally presence of cellulose in substrates such as garbage and waste paper are insoluble, but products of cellulose hydrolysis are available as carbon and energy sources for other microbes that inhibit environments in which cellulose is biodegraded and this availability forms the basis of many microbial interactions that occur in anaerobic environments and are a good source of Bioenergy [5]. Increasing the proportion of FVW from 20% to 50% improved the methane yield from 0.23 to 0.45 m^3 CH_4 Kg^{-1} VS_{added} and caused the volatile solid reduction to decrease slightly with the loading rate maintained in the range 3.19-5.01 kg volatile solid per cubic meter per day (kg VS m^{-3} D^{-1}) [6]. The anaerobic digestion of different volatile solid mixtures of tomato-plant waste and rabbit waste shows that the methane production increases when the volatile solid concentration of tomato-plant waste increases in the mixture. The addition of the tomato plant waste to the latter in proportion higher than 40 percent improves the methane production obtained from the animal waste alone [7].

Among the various fruits and vegetable solid waste tested in the study, most of the varieties of mango peels, citrus wastes, etc exhibited methane yields significantly higher than the cellulose and conversion kinetics higher at 35°C than at 28°C [3]. Between 60 and 100 kg TS and loading rate of ensilaged and dried mango peel, the yield of Biogas was 0.6 to 0.5 m^3 /kg VS added and 45 to 42 m^3/kg VS added respectively [8]. Biogas production increased with increasing Co^{2+}, Ni^{2+} concentrations in the

Corresponding Author: S. Anhuradha, Department of Chemical Engg, Annamalai University, India.
E-mail: anhuradha@yahoo.co.in

feed up to 125 mg/L there after it decreased gradually. Higher yield of 0.39m^3/kg VS added with 4000 mg/L of $FeCl_3$ with 56% methane content [9].

The ensilaging of pine apple peels for a period of 6 months resulted in the biogas yield of 0.67 m^3/ kg VS added with methane content of 65% since they are rich in carbohydrate and proteins [10]. Microbiological pre-treatment of mango peels with 6% TS, the biogas yield was 0.36m^3/Kg VS with a methane content of 58%. The results suggested that the microbiological pre-treatment of mango peel would have a significant influence on the economics of the process [11]. For methanogenic fermentations, the Chen and Hashimoto model is appropriate for determining the theoretical yield of the product and can be used to assess the working efficiency of digester and describe steady-state volumetric production rate of methane [12, 13]. Two important equations of the Ken and Hashimoto equation is:

$$\frac{S}{S_o} = \frac{K}{\frac{J}{J_m} - (1+K)} \qquad (1)$$

$$r_{CH_4} = \frac{B_o \quad S_o}{J}\left(1 - \frac{K}{\frac{J}{J_m} - (1+K)}\right) \qquad (2)$$

Where:

S_o is influent volatile solids (VS) concentration (g/L). S is substrate (effluent volatile solids (VS) concentration (g/L) K is the kinetic constant. J is retention time (optimum) days. J_m is minimum retention time (days). B_o is ultimate yield of CH_4 (CH_4 (STP)/g. VS).

The methane gas can be used to produce either thermal energy or electrical energy by passing through generators or other purposes in the plant in terms of energy saving. Therefore, this research will focus on the feasibility of biogas generation by anaerobic digestion of mango peel. The objective of this study was to investigate the anaerobic treatability and methane generation potential of mango pulp processing industry solid wastes by performing a biochemical methane potential test and to examine the process kinetic and digester efficiency of anaerobic batch fermentation of mango peel by Ken and Hashimoto model. To evaluate the performance of the total solids anaerobic digestion process using different ratios of mango peel and cow dung. The result of this study can be applied for further co-digestion of agro industry wastes for energy saving.

MATERIALS AND METHODS

Substrate: Solids waste (mango peel) was collected from the mango pulp processing industry located near Dharmapuri, Tamil Nadu. Mango peel was sundried for 30 days ground to fine particles using a grinding mill and screened through pore size of 1 mm. The samples were stored at room temperature until use.

BMP Tests

Laboratory Digesters: BMP experiments were performed in 500 ml serum bottles capped with rubber sleeve stoppers. Every serum bottles was seeded with 20 ml of the inoculum. Alkali was added to the digester to maintain neutral pH which might drop due to VFA generation. The C/N weight ratio of the organic matter was adjusted to 25:1 using urea, as this is the optimum ratio for maximum microbial activity [14]. Since mango peel is deficient in nitrogen, the feed was always supplemented with 2% urea by weight of total solids. Methanogens have specific growth requirement for iron. Hence one gram of $Fecl_3$ was added to the each bottle. After the addition of substrates, water was added to the serum bottles to make the final % total solids. The serum bottles were finally purged with a 25% CO_2 and 75% N_2 gas mixture for 3-4 min to maintain the proper pH and anaerobic condition. The bottles were kept at 35 ± 2°C in a temperature controlled room for incubation and gas production in each bottle was measured by a water displacement method.

Start-up: The digesters were initially charged with Cow-dung slurry diluted with water in the proportion of 4:5 together with a 10% inoculums obtained from pre-digested cow dung. It was added to the each reactor to initiate the digestion. For each set a different proportions of mango peel and cow dung in the ratios of 1:2, 1:5, 1:10 were added. For each set of ratios the digestion mixtures had final concentrations ranging from 4, 6, 8, 10 & 12%.

Analytical Methods: Total solids, volatile solids, Volatile fatty acids (by steam distillation method) and pH, cellulose, Hemi cellulose, Ash was determined by standard methods as described in the methods of APHA [17]. The total volume of gas produced was measured at a fixed time in each day by water displacement method [4]. Gas samples were collected by gas sampling injector and a sample of 1 ml was used for each run. The biogas composition was determined using gas chromatograph with a packed column and thermal conductivity detector (TCD), using a Propak Q column.

RESULTS AND DISCUSSION

Characteristics of Mango Peel: Total carbohydrates including hemicelluloses, celluloses and reducing and non-reducing sugars content of dried mango peel is shown in Table No: 1. The composition of mango peel is rich in fermented sugars and other component of carbohydrates, but it is deficient in Nitrogen and trace elements. The some proportions of the sugars and volatile fatty acids indicated that most of the soluble fraction consists of complex molecules which must be broken down into simpler molecules before they can be taken up by microorganisms.

Table 1: Proximate Composition of Solid Wastes (Mango peel)

Characteristics (%)	*Mango peel*
Moisture	08.2
Total Solids	91.8
Volatile Solids	92.3
Ash	07.7
Cellulose	6.0
Hemi cellulose	17.62
Protein	4.0
Reducing Sugar	38.09
Non-Reducing Sugar	5.98
Lignin	12

Effect of Loading Rate on Biogas and Methane Production: In this study, BMP tests were performed in order to investigate the biogas generation potential of different % TS of mango peel with cow dung. The digesters were operated for a period of 50 days for each loading rate and terminated when no significant gas production was observed over a 2 week period. The effluent characteristics were determined finally.

The cumulative gas production values of the serum bottles are shown in Figure 1. But Gas production in most of bottles extended after 40days [15]. The initial biogas yield was low for all the ratio of feed; it rose slowly and became almost stable after the three weeks of digestion. The methane content in the biogas gradually increased from the 57% to 78%. Biogas production increased with increasing loading rate and then decreased. However, the highest yield of 5.3926 m^3/Kg VS added at a loading rate of 80 Kg TS /m^3. Between 4% to 12% TS of dry mango peel, the biogas yield was in the range of 2.43 to 0.6036 m^3/kg VS added,1.265 to 0.6540 m^3/Kg VS added and 4.966 to 1.7003 m^3/Kg VS added for the ratios of CD: MP 1:2,1:5 and 1:10 respectively. A biogas production of 0.6 to 0.5 m^3/Kg VS added has been reported for the mango peel [8]. The highest yield of biogas is due to the addition of inoculum and some proportions of cow dung to mango peel. Addition of cow dung increases the microbial population in the digesters. The yield of biogas produced is depicted in Figure 4.

Effect of Ph and Vfa on Biogas Yield: The total production of biogas depended on the availability of organic constituents of the feed to the digester. From the results of the start up experiments, it can be concluded that mango peel produced improved stability of the digesters, although the VFA content in the feed was very low. The examination of the effluent showed a characteristic pattern and the pH and VFA were always in the range of 6.1 to 7.5 and 368 to 868 mg/litre respectively. Biogas production increased with the loading rate. The yield was highest, however, at the lower loading rates of 6% to 8% and then decreased gradually. This was associated with a drop in pH at higher loading rates and consequently increased levels of VFA were shown in Figure 5 and 6.

A linear effect of loading rate on the rate of biogas generation and volatile solids utilisation was observed, but as the loading rate increased, the volatile solids content of the effluent also increased. The methane percentage increased as the loading rate was increased, but there was an increase in the rate of biogas production. A slurry containing 6% to 10% TS could be handled easily for biogas production although the higher concentrations of total solids led to handling problems and choking of the digesters [8]. As well as generating biogas, anaerobic digestion should reduce the VS concentration of the solids. A reduction in the VS concentration did occur in all the digestions. Although there were some extremes in general, the reductions were in the range of 98% to 99%. But this shows the higher reductions in the volatile solids, when compared well with the VS reductions which have been reported by other workers examining digestion. [16].

Process Kinetics and Digester Efficiency: The daily biogas production profiles for the batch fermentation of mango peel with cow dung for 10% TS is shown in Figure 7.

The graph shows that the organic wastes available from the mango peel contains easily biodegradable organic matter and this contributed to a better biogas yield. The rate kinetics is controlled by mixed factors such as sources of carbon (acetate and intermediates, propionate and butyrate). The carbon sources accumulate

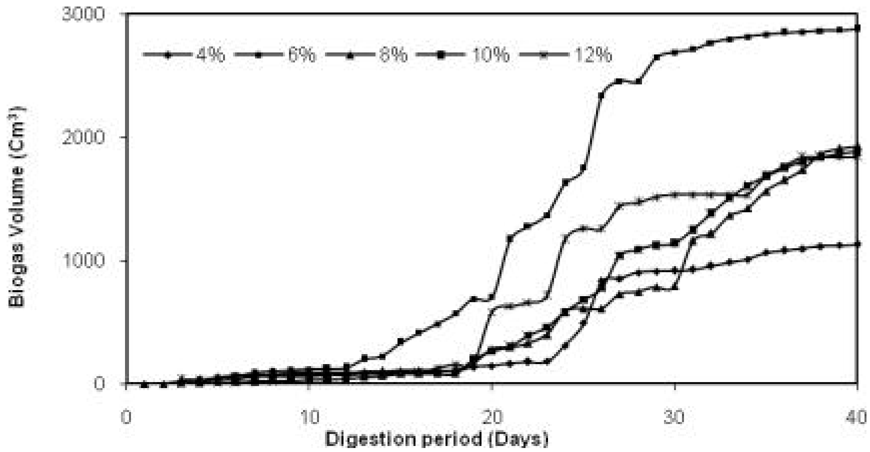

Fig. 1: Time course of anaerobic digestion using mango peel (CD: MP 1:2)

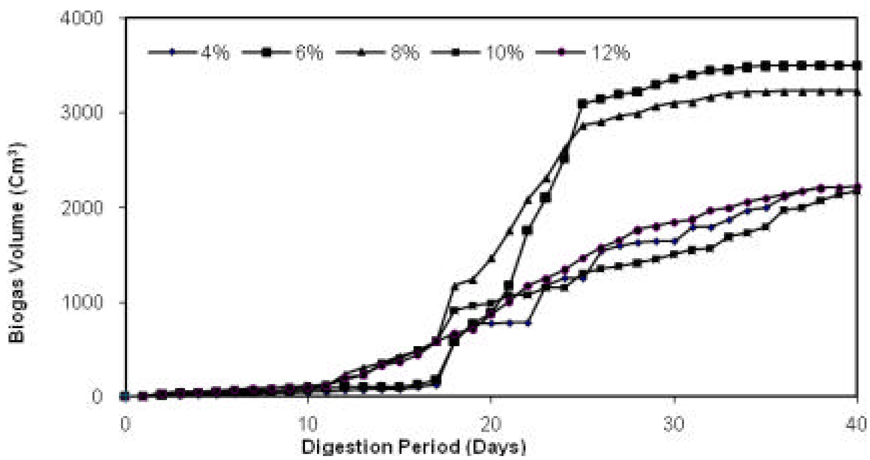

Fig. 2: Time course of anaerobic digestion using mango peel (CD: MP 1:5)

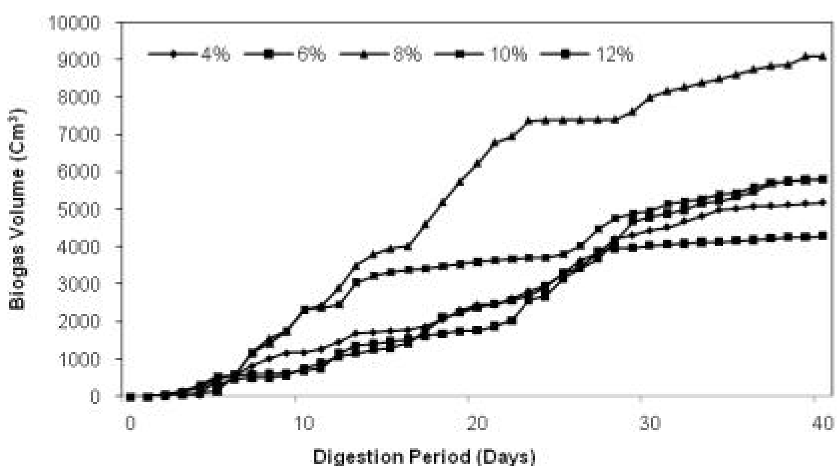

Fig. 3: Time course of anaerobic digestion using mango peel (CD: MP 1:10)

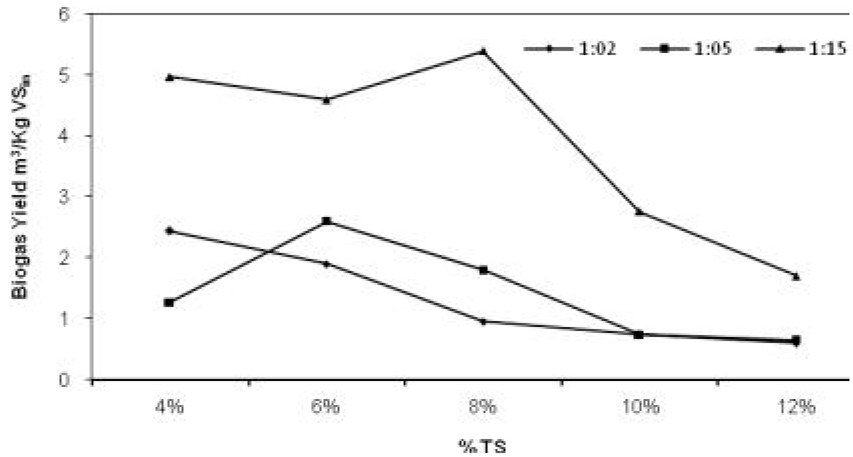

Fig. 4: Influence of loading rate on Biogas Yield

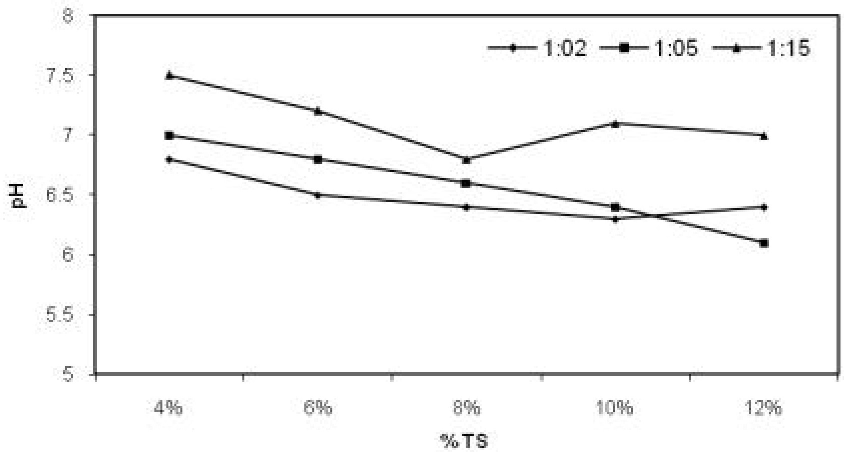

Fig. 5: Influence of loading rate on pH

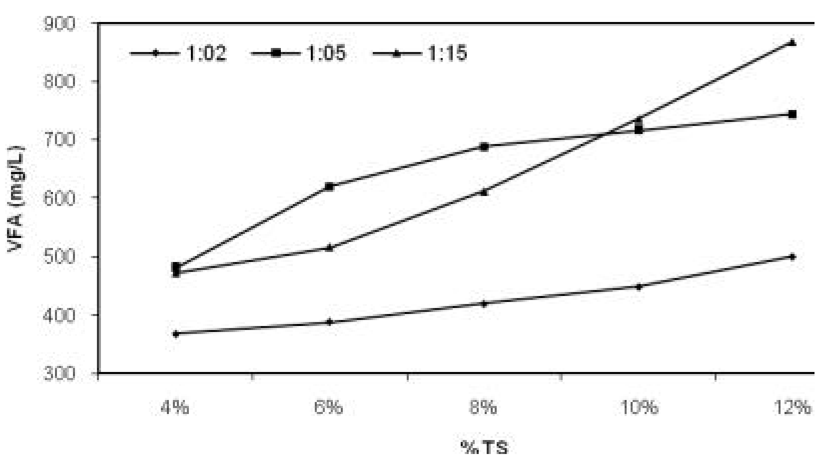

Fig. 6: Influence of loading rate on VFA

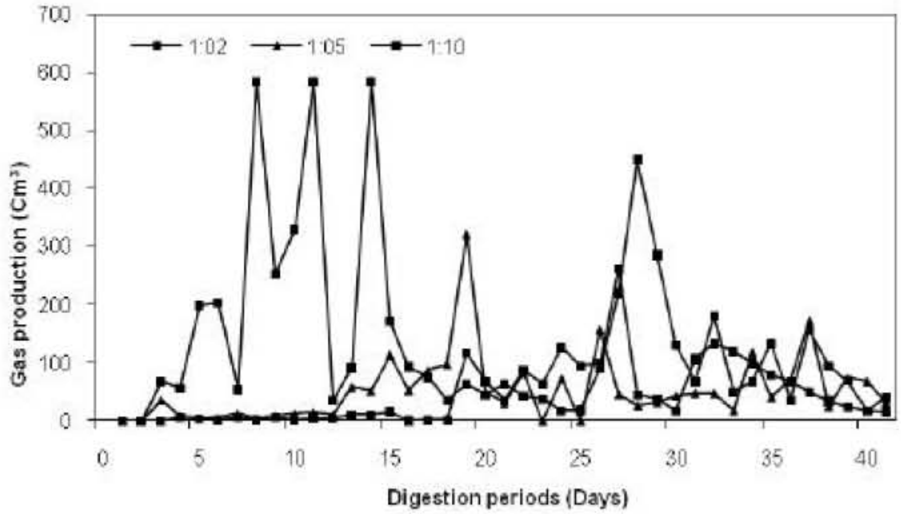

Fig. 7: Daily biogas production

Table 2: The process kinetics and digester efficiency for 8% TS.

Ratios	Influent VS Concentration S_o(g)	Effluent VS Concentration S(g)	Kinetic constants K	Theoretical Yield r_{CH4}	Digester Efficiency (%)
1:2	2.029	0.0231	0.01244	0.0285	54.42
1:5	1.793	0.0503	0.0302	0.0466	62.64
1:10	1.686	0.0357	0.0622	0.1325	66.14

to toxic levels in the medium. In particular, propionate is reported to be toxic to bydrogen utilizing bacteria. The effect of these factors on rate kinetics leads to mixed order kinetics. Because of the conversion of other volatile acids to acetate, the rate kinetics of the biogas production returns to first order. The first order to mixed order is maintained through the methanation. The reduction is VS in the three ratio were in the range of 96% to 98%. These values are comparable with the VS reductions reported for the other types of wastes. As expected the specific gas production for mango peel was higher (5.3926 l biogas / g VS in and 5.5093 l biogas / g VS des) for the 1:10 ration at 8% TS than for the 1:2 ratio 2.0342 l biogas/g VS in and 2.4535 l biogas/g VS des at 4% TS. Consequently, the specific gas production for the mango peel, co-digestion with cow dung for the 1:10 at 8% TS was higher, compared to other values.

Table (2) summarizes the process kinetics and digester efficiency of anaerobic digestion of mango peel and cow dung. Batch kinetics of anaerobic digestion is useful in predicting the performance of digesters and for the design of appropriate digesters. Kinetic studies are also helpful in understanding inhibitory mechanisms of biodegradation.

CONCLUSIONS

The use of dried mango peel as co-digestate with cattle slurry produced an increase in the methane yield, compared with that of a control digestion using cattle slurry alone [8] and strongly favours the anaerobic digestion.

The substrate at a concentration of 6 to 10% TS increased the methane yield, but higher % of TS depressed the methane yield. Anaerobic co-digestion of mango peel with cow-dung seems to be an attractive method for waste management environmental production and energy savings.

REFERENCES

1. Anthony Mshandete, Lovisa Bjornsson. *et.al*. 2006. Effect of particle size on biogas yield from sisal fibre waste, Renewable Ener., 31: 2385-2392.
2. Keshtkar, A., B. Meyssami, *et.al*. 2003. Mathematical modelling of non-ideal mixing continuous flow reactors for anaerobic digestion of cattle manure, Bioresource Technol., 87: 113-124.
3. Nallathambi, V. Gunaseelan, 2004. Biochemical methane potential of fruits and vegetable solid waste feedstocks, Biomass and Bioen., 26: 389-399.

4. Selina, E. Kavitha, *et.al.* 2007-2008. Biomethanation of vegetable wastes, J. the IPHE, India, 3: 9-11.
5. David, A. Stafford, Dennis L. Hawkes and Rex Horton, 1980. Methane production from organic waste, USA: CRC. press.
6. Callaghan, F.J., D.AJ. Wase, K. Thayanithy and C.F. Forster, 2002. Continuous co-digestion of cattle slurry with fruit and vegetable wastes and chicken manure, Biomass and Bioen., 22: 71-77.
7. Trujillo, D., J.E.P erZ and F.J. Cebreros, 1992. Energy recovery from waste. anaerobic digestion of tomato plant mixed with rabbit waste, Bioresource Technol., 45: 81-83.
8. Madhukara, K. , Krishna Nand, *et al.* 1993. Ensilage of mangopeel for methane generation, Process Biochemis., 28: 119-123.
9. Raju, N.R., S. Sumithra Devi. *et al.* 1991. Influence of trace elements on biogas production from mango processing waste in 1.5m^3 KVIC digesters, Biotechnology Lett., 13: 461-464.
10. Swaroopa Rani, D. and Krishna Nand, 2004. Ensilage of pineapple processing waste for methane generation, Waste Manage., 24: 523-528.
11. Sumithra Devi, S. and Krishna Nand, Microbiological pretreatment of mango peel for biogas production, J. Microbial Biotechnol., 4(2): 110-115.
12. Anhuradha, S., V. Vijayagopal, P. Radha and R. Ramanujam, 2007. Kinetic Studies and Anaerobic Co-digestion of Vegetable Market Waste and Sewage Sludge, Clean-Soil, Air. Water, 35(2): 197-199.
13. Ezeonu, F.C. and A.N.C. Okaka, 1996. Process Kinetics and Digestion Efficiency of Anaerobic Batch Fermentation of Brewer's Spent Grains (BSG), Process Biochemis., 31(1): 7-12.
14. Roa, M.S., S.P. Singh. *et al.* 2000. Bioenergy conversion studies of the organic fraction of MSW:assessment of ultimate bioenergy production potential of municipal garbage, Applied Ener., 66: 75-87.
15. Isci, A. and G.N. Demirer, 2007. Biogas production potential from cotton wastes, Renewable Ener., 32: 750-757.
16. Callaghan, F.J. D.A.J. Wase, *et al.* 1999. Co-digestion of waste organic solids: batch studies, Bioresource Technol., 67: 117-122.
17. Greenburg, A.E., L.S. Clesceri and A.D. Eaton, 1992. Standard Methods for the Examination of Water and Wastewater, 18th ed. American Public Health Association, (APHA), D.C., Washington,