COMPOSITION AND ANAEROBIC DIGESTION OF SINGLE AND COMBINED ORGANIC FRACTIONS OF MUNICIPAL SOLID WASTE OF DAR ES SALAAM

AK Kivaisi and J Mukisa
Applied Microbiology Unit, University of Dar es Salaam,
P.O. Box 35060, Dar es Salaam, Tanzania

ABSTRACT

The composition of major categories of municipal solid waste (MSW) of Dar es salaam city was determined. Food remains and vegetable matter constituted 80-90% of the categories. Organic fractions of the individual categories contained 18-20 % total solid (TS), 30-50 % (dry weight) total fibre and 1-1.3 % nitrogen. The assorted organic fractions were tested for anaerobic conversion into biogas at 55°C in batch cultures for 14 days with a mixed population of microorganisms. At a substrate concentration of 6-8 g volatile solids per litre fermenter volume (g VS l-1 FV) individual fractions were degraded by 51-75% and gave methane yields in the range of 390-492 ml per gram VS added. Combining individual fractions with chicken manure at a ratio of 1:1 (TS) increased the N-content of the fractions by 16-133% and the VS content of the fermenting substrate doubled. Overall methane production by the combined fractions increased by 8-20% over that measured for the individual fraction incubations, but methane yields decreased by 30-50%. The mixed waste category constituting a substrate concentration of 6 g VS l-1 FV was degraded by 65% and gave a yield of 428 ml CH4 per gram VS added. This study concludes that individual fractions of MSW of Dar es salaam city are suitable as feedstocks for biogas digesters. The decreased overall conversion of the fractions when combined with chicken manure was attributed to high ash content of the manure.

INTRODUCTION

Conversion of organic fractions of municipal solid waste (MSW) to biogas is a technology which can be integrated in an overall waste treatment system (Cecchi & Meta-Alvarez 1991, Ahring 1994). However, this process has been characterized by low overall organic matter conversion efficiencies and low biogas yields. Among the identified causes leading to poor performance of anaerobic digestion of lignocellulosic materials include: (i) crystallinity of cellulose which is often the major component; (ii) lignin which limits the extent of digestion by protecting the easily degradable polysaccharides from enzymatic attack; (iii) low enzyme activities in the digesters and (iv) low nutrient levels, especially nitrogen (Op den Camp *et al.* 1988, Pavlostathis & Giraldo-Gomez 1991). In order to enhance the process, co-digestion is applied. Thermophilic co-digestion of bulk MSW fractions with minor fractions such as manure, slaughter house wastes and bleaching clay has been shown to increase biogas output significantly (Marique *et al.* 1989, Madamwar *et al.* 1990, Rivard *et al.* 1990, Ahring *et al.* 1992, Ahring 1995). Other advantages of thermophilic digestion over mesophilic digestion include a high sanitizing effect, resistance to ammonia toxicity, and a better overall economy over mesophilic processes (Mathrani *et al.* 1994, Angelidaki & Ahring 1993 1997). Furthermore, the treated waste after thermophilic digestion is a well stabilized fertilizer for use on farms (Ahring *et al.* 1992).

The MSW of Dar es Salaam city is comprised of wastes from households, markets, hotels, industries, hospitals, slaughterhouses, shops and construction works. The current method of their disposal is by landfilling. This disposal is poorly planned and poses a significant environmental problem. Since the bulk of the waste has high moisture content, its conversion into biogas is attractive. A medium scale pilot plant for biogas production from mixed organic waste was proposed for Dar es Salaam (Anon. 1993). Prior to the commissioning of this plant, it is important to know the composition of the waste fractions to be used as feed stocks and their methane production potentials.

This study determined the composition and digestibility of the various waste fractions and the effect of digestion of the fractions with chicken manure on overall conversion to methane at 55°C. The study also examined the overall conversion of mixed waste to methane.

MATERIALS AND METHODS

Waste collection and characterization

Waste was collected and sorted out into the source categories of market places, breweries, hotel kitchens, households, a poultry factory, edible oil refinery and a slaughterhouse in Dar es Salaam city.

From each category, the components of one kg of well mixed waste sample were quantified. Physical components such as vegetable matter, food remains, glass, metals, paper, plastics or paper were separated by hand. After sorting, each organic fraction of the waste samples was shredded using a blender to particles of about 2 mm in size, and the portions used for fermentation trials. Left over portions were stored at -20°C until chemical analysis was carried out.

Inoculum

The inoculum used was sludge obtained from under a decomposing refuse heap at a market place. Shortly before use, the inoculum was filtered though a cheese cloth to remove solid particles.

Culture medium

The culture medium was prepared from the following stock solutions (chemicals in g/l of distilled water):(A) $(NH_4)HCO_3$, 4.0; $NaHCO_3$, 35.0; (B) $Na_2HPO_4.2H_2O$, 7.15; KH_2PO_4, 6.2; $MgSO_4.7H_2O$, 0.6 ; (C) $CaCl_2.4H_2O$, 13.2; $MnCl_2$. $4H_2O$, 10.0; $CoCl_2.6H_2O$, 1.0 ; $FeCl_3.6H_2O$, 8.0. (D) Cysteine-HCl, 625 mg/95 ml distilled water ; $Na_2S.9H_2O$, 625 mg/95 ml distilled water. To 480 ml distilled water, the following stock solutions were added: A, 240 ml; B, 240 ml, C, 0.12 ml; D, 38 ml. Rezasurin (1 ml of 0.1 %) was used as a redox indicator.

Experimental conditions and fermentation

The various MSW organic fractions were digested singly or combined in three experiments as follows:

1. Single fraction digestion in which the fermentation mixture was composed of two grams (fresh weight) of a fraction, 40 ml of fermentation medium and 10 ml of inoculum in 125 ml serum bottles.
2. Co-digestion in which one gram of the individual organic fractions were each co-digested with one gram of chicken manure in 125 ml serum bottles with 10 ml inoculum and 40 ml fermentation medium (total 2 g).
3. Mixed waste digestion in which all the fractions were combined with abattoir waste and bleaching clay in well defined proportions (Table 1) in 250 ml serum bottles with 80 ml medium and 20 ml of inoculum. The composition of the fermentation mixtures are shown in Tables 1 and 2.

Table 1: Composition of fermentation mixture* for mixed waste in 100 ml fermentation volumes. The materials were collected in Dar es Salaam, Tanzania. 1996

Fraction	% Composition	Weight (or volume) (wet weight)
Domestic	24.4	0.976 g
Market	34.2	1.368 g
Hotel kitchen	1.7	0.068 g
Abbatoir	4.8	0.184 g

Table 1 (Continued)

Fraction	% Composition	Weight g(or volume ml) (wet weight, g)
BSG	24	0.96
Bleaching clay	7.9	0.32
Medium	80 v/v FV[a]	80
Inoculum	20 v/v FV	20

* : total volatile solids content = 0.619 g

[a] : volume per fermenting volume

Table 2: Volatile solids (VS) contents for individual and co-digestion incubation with chicken manure. The materials were collected in Dar es Salaam, Tanzania 1996

	VS content (g)	
Source	Single fraction	Mixed with chicken manure
Hotel kitchen	0.380	0.627
Market	0.275	0.534
Domestic	0.303	0.565
BSG[a]	0.319	0.568

chicken manure VS content was 0.483 g

BSG = Brewery spent grains

All bottles were closed with n-butyl stoppers and sealed with aluminium caps. They were then flushed with oxygen free nitrogen for 10 min and incubated at 55°C with shaking (200 rpm) for 14 days. The experiments were repeated with duplicate bottles. The extent of digestion was measured by determination of loss of volatile solids, production of volatile fatty acids and methane. Total solids (TS) and volatile solids (VS) were determined according to standard methods (Clesceri *et al.* 1989). Neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose, hemicellulose, lignin (permanganate method) and ash content were analyzed according to Goering and van Soest (1970). Kjeldahl nitrogen was determined according to Arthur (1978).

Methane content and volatile fatty acids (VFA) were measured by gas chromatography according to Hutten *et al.* (1981) and Teunissen *et al.* (1989), respectively.

Statistical analysis

Statistical analysis was carried out by using INSTAT software package (1990-1993) GraphPad V2.04.931842B.

RESULTS AND DISCUSSION

Substrate composition

Vegetable matter and food remains were the dominant components (83-94 %) of all the major waste categories. Their chemical compositions are shown in Table 3. The Kjeldahl nitrogen contents of the substrates used in the single and co-digestion experiments are presented in Table 4. By mixing the individual fractions with chicken manure an increase of 16-133 % in N-content over the individual respective fractions was observed.

Table 3: Chemical composition* (means ± SD[a]) of organic fractions of major MSW categories. The materials were collected in Dar es Salaam, Tanzania. 1996

Determination	Market	Domestic	Hotel	Manure	BSG[b]
Total solids	18.6±4.0	17.9±2.3	20.8±3.1	81.2±4.4	17.6 ± 5.0
Volatile solids	74.1±5.3	84.8±9.8	91.5±3.9	59.5±8.6	90.7 ±4.1
Ash	25.9±5.3	15.2±9.5	8.5±3.0	40.5±8.7	7.0 ±1.4
NDF	49.0±8.1	37.9±1.3	21.7±13.0	ND	47.9±14.1
ADF	18.8±6.0	17.7±5.9	11.4± 4.4	ND	11.4 ±3.9
Cellulose	31.4±5.6	11.2±2.6	7.7±3.0	ND	6.4 ±1.2
Hemicellulose	17.6±4.2	20.2±1.3	35.3±13.0	ND	36.5±14.1
Lignin	9.3±2.6	10.0±2.4	6.1±2.4	ND	8.1 ±2.1
Nitrogen	1.05±0.2	1.3 ±0.4	0.97±0.07	3.1 ± 1.4	0.73±0.2

*: % dry weight

[a]: n= 6

[b]: Brewery spent grains

NDF: neutral detergent fibre

ADF: acid detergent fibre

ND : not determined

Table 4. Nitrogen content (mean ± SD [a]) of substrates for single and co-digestion of materials collected from Dar es Salaam, Tanzania. 1996

	Kjedahl nitrogen (% dry weight)		
Waste category	Single	Mixed with manure	t- test
Market	1.05 ± 0.2	1.22 ± 0.4(16)	n.s.
Hotel	0.94 ± 0.07	1.79 ± 0.6(90)	p =<0.05
Domestic	1.34 ± 0.4	1.82 ± 0.7(35)	n.s.
BSG	0.73 ± 0.2	1.7 ± 0.5(133)	p =< 0.05
Manure	3.1 ± 1.4		

[a]: n=4
Values in brackets are % increase in N-content
n.s. = not significant

Total methane production
Amounts of methane produced from the tested waste categories after 14 days of incubation varied both within a given treatment and among treatments as shown in Figure 1. For single waste digestion the mean volumes of methane produced ranged between 2.8 and 3.1 litres per litre of fermenting volume ($l.\ l^{-1}$ FV). The least volume was obtained from chicken manure and the highest volume was obtained from brewery spent grains (BSG). Methane production for the co-digestion incubations ranged between 2.7 and 3.5 $l\ l^{-1}$ FV whereby the least volume was from BSG-manure combination and the highest from hotel kitchen waste-manure combination. Although co-digestion incubations gave slightly higher methane yields than single waste incubations in the range of 8-20 %, the difference was not significant ($P > 0.05$) Digestion of mixed waste category produced a mean methane volume of 2.65 $l.\ l^{-1}$ FV.

Specific amounts of methane produced per gram volatile solids (gVS) added are presented in Table 5. Yields obtained for single fractions and mixed waste incubations were 30-50 % higher than those obtained for co-digestion incubations.

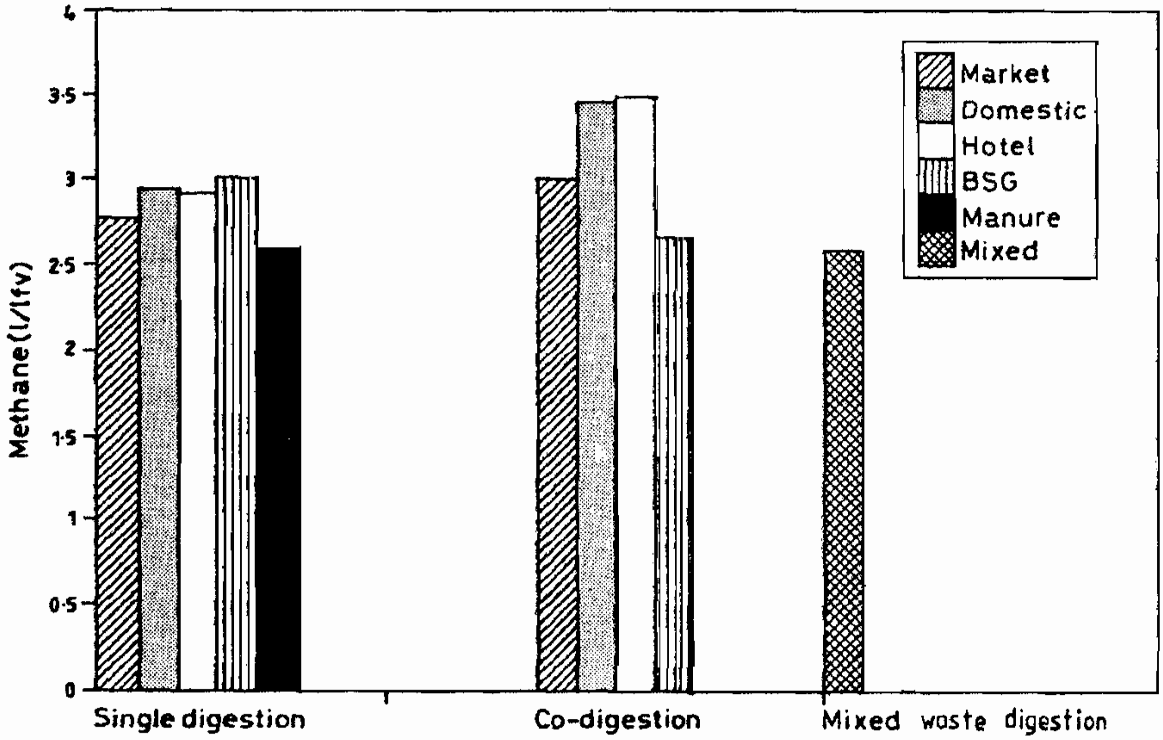

Fig. 1: Total methane production by various MSW fractions after 14 days incubation, Dar es Salaam 1996

Table 5. Mean specific methane production* from individual, co-digestion and mixed waste incubations for waste materials obtained from Dar es Salaam, Tanzania. 1996

Treatment	Waste fraction	Specific production ml CH_4 g^{-1} VS
Single waste	Hotel kitchen	390
	Market	375
	Domestic	492
	BSG	479
	Chicken manure	461
Co-digestion	Hotel kitchen	262
	Market	245
	Domestic	276
	BSG	211
Mixed waste digestion		428

* Calculated values
BSG = brewery spent grains

Trend of volatile fatty acids and methane production

The trend of digestion performance for co-digestion and mixed waste category digestion treatment is shown in Figure 2. Daily methane production and total volatile fatty acids levels are shown counter matched.

Generally for all waste categories in the co-digestion treatment, the total volatile fatty acids concentrations peaked between the fourth and sixth day, followed by a sharp drop to the eighth day of incubation (Fig. 2a). This was followed by a second peak which dropped to the 14th day of incubation. Mixed waste incubation showed only one peak between 4th and 5th days which dropped sharply to the 7th day, and thereafter became relatively stable up to the end of the incubation period (Fig. 2c). However, methane production showed a single peak for both treatments which rose as the total volatile fatty acid dropped (Fig. 2b, d) .

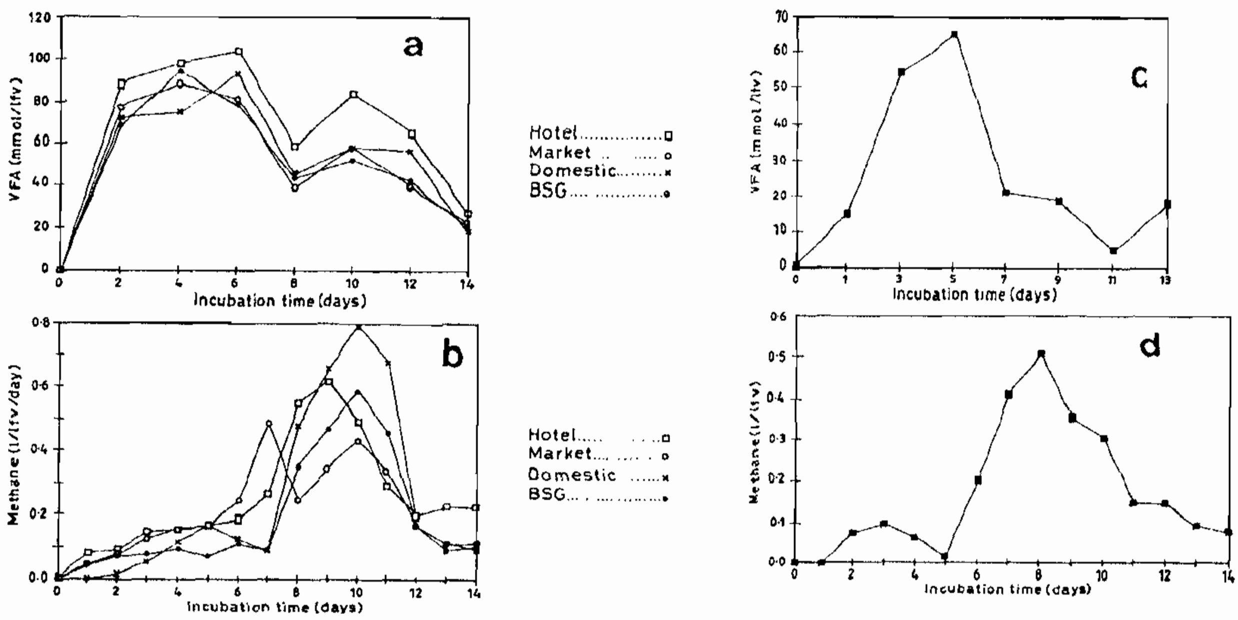

Fig. 2: Trends of production of volatile fatty acids and methane during the digestion of combined and mixed waste: a and b, co-digestion incubations; c and d, mixed category incubation

Volatile solid removal efficiency

The extent of volatile solid (VS) removal for single, co-digestion and mixed waste category treatments are shown in Figure 3. Generally, in the single waste incubations the extent of VS degradation was significantly higher ($P<0.05$) than that of the co-digestion incubations. For mixed waste incubations, VS degradation was significantly higher than in the co-digestion incubations but similar ($P>0.05$) to that obtained for single digestions. Of all the treatments, the single waste digestion of hotel kitchen waste gave the highest degradation extent of 73.3%.

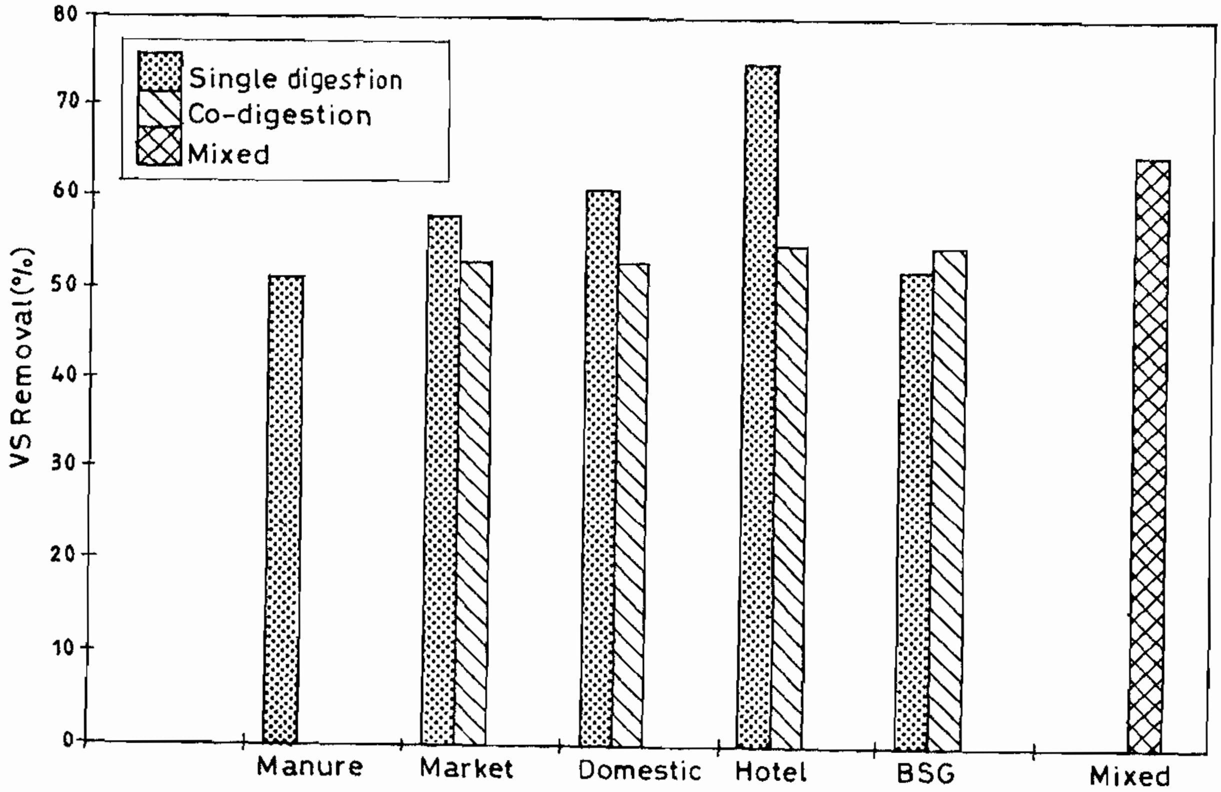

Fig. 3: The extent of removal of volatile solids obtained for various waste fractions after 14 days incubation. The waste material was obtained in Dar es Salaam. 1996

DISCUSSION

The suitability of an organic material as a feedstock for biogas digesters is judged on the basis of its overall degradability and hence its methane production potential. This study has demonstrated the various organic fractions of MSW of Dar es salaam to be suitable as feedstocks for biogas digesters. The fractions were degraded by 52-73 % and gave methane yields in the range of 390-492 ml g-1 VS added. These values are similar to a theoretical methane yield of 415 ml g-1 VS for carbohydrates. This extent of conversion is also comparable to that achieved previously (300 ml CH4 g-1 VS) for MSW components (Owens & Chynoweth 1993).

This study observed significantly higher extents of VS removal of single waste fractions and mixed waste than of co-digested waste fractions. The specific methane yields per g VS of co-digested waste added were considerably reduced compared to those observed for the single waste fractions and mixed waste. By mixing chicken manure with the fractions, VS content was doubled and N-content was markedly improved. A significant increase in methane production was therefore expected from the incubations. The lower methane yields obtained for the co-digestion incubations may be explained by the high ash content of manure used. It is likely that the availability of the degradable organic matter to the microorganisms and overall enzymatic attack was limited by the high silica content which was previously shown to affect degradability of rice straw (Lequerica *et al.* 1984). The same reasoning may explain the relatively low extent of degradation achieved for the single chicken manure fraction. Previous studies (Ahring *et al.* 1992) achieved marked increases in methane production by mixing cow manure with household waste. The difference in the results was most likely due to differences in composition of the manures used. The observation that BSG fraction when co-digested with chicken manure even showed a negative value of 11% in methane production may have been also due to an unfavourable C:N ration which was attained. The N-content of the mixed substrate was increased by 130% over the initial one. The resultant C:N ratio of the substrate was, however, not determined.

The extent of degradation of mixed waste was significantly higher than that of co-digestion incubations (except for hotel waste which showed a higher degradation extent). The methane yields of the mixed waste were almost twice as much as those of co-digestion incubations. Considering the nature of the minor components in the mixed waste category namely, edible oil bleaching clay and abattoir waste, better results were expected.

Improved performance of thermophilic digestion, with respect to gas yield and stability, has been observed in large scale biogas plants in Denmark, after addition of a similar product called bentonite bound oil, a waste product from an oil refinery factory (Angelidaki *et al.* 1990). The increase was attributed to high fat content of the additives. Methane yields from oils are much higher than from most other organic materials. The theoretical gas yield of lipids is 1014 ml g-1 (Wang & Jeris 1976) which makes it a very attractive substrate for biogas production. On the other hand, long chain fatty acids which are the anaerobic degradation products of fats and oils have been reported to cause inhibition of bacterial growth and methane production at very low concentrations (Hanaki *et al.* 1981). Angelidaki *et al.* (1990) reported inhibition of methanogenesis by oil at concentrations higher than 2 g. l^{-1}. These observations indicate that there is a critical amount of fat rich additives required to stimulate methane production. In this study, the total concentration of the fats in the digestion mixture was not determined, and hence the effect of the oil rich components on overall degradation and methane yields could not be determined.

From the results of this study, it is concluded that individual organic fractions of MSW of Dar es salaam city are suitable as feed stocks for biogas digesters. The nutritional status of the fractions in terms of N-content may be improved by supplementing with animal manures which contain high N and VS content.

ACKNOWLEDGEMENTS
The authors wish to express their gratitude to NUFFIC, the Netherlands for sponsoring this study.

REFERENCES

Ahring BK 1994 *Status of science and application of thermophilic anaerobic digestion.* Proceedings of the seventh international symposium on anaerobic digestion, Cape Town, South Africa. pp. 328-347

Ahring BK 1995 Methanogenesis in thermophilic biogas reactors. *Ant. van Leeuwenhoek.* 67:91-102

Ahring BK, Angelidaki I and Johansen K 1992 Anaerobic treatment of manure together with industrial waste. *Wat. Sci. Technol.*

Angelidaki I and Ahring1993 BK Thermophilic anaerobic digestion of livestock waste: the effect of ammonia. *Appl. Microbiol. Biotechnol.* 38:560-564

Angelidaki I and Ahring BK 1997 Co-digestion of olive oil mill wastewaters with manure, household waste or sewage sludge. *Biodegradation.* 8:221-226

Angelidaki I, Petersen SP and Ahring BK 1990 Effects of lipids on thermophilic anaerobic digestion and reduction of lipid inhibition upon addition of bentonite. *Appl. Microbiol. Biotechnol.* 33:469-472

Anon. 1993 *Takagas: Energy from waste,* Tanzania, UNDP

Arthur V 1978 *A textbook of quantitative inorganic analysis.* Forth ed. Longmann Press, London

Cecchi F and Meta-Alvarez J 1991 Anaerobic digestion of municipal solid waste: an up-to-date review. In: H.W., Doelle, D.A. Mitchell, C. Rolz (eds). *Solid Substrate Cultivation*, Elsevier Science, Amsterdam

Clesceri LS, Greenberg AE and Trussell RR 1989 *Standard methods for the examination of water* (17th Edition). Port City Press, Baltimore, USA

Goering HK and van Soest PJ 1970 *Forage fibre analysis.* USDA, ARS, Agric. Handbook No. 379

Hanaki K, Matsuo T and Nagase M 1981 Mechanism of inhibition caused by long chain fatty acids in anaerobic digestion process. *Biotechnol. Bioeng.* 23:1591-1610

Hutten TJ, de Jong MH, Peeters BPH, Van der Drift C and Vogels GD 1981 Coenzyme M (2-mercapto ethane sulfonic acid)-derivatives and their effects on methane production from carbon dioxide and methanol by cell-free extracts of *Methanosarcina barkeri. J. Bacteriol.* 145: 27 34

Lequerica JL, Valles SS and Lors AF 1984 Kinetics of rice straw fermentation. *Appl. Microbiol. Biotechnol.* 19:70-74

Madamwar D, Patel A and Patel V 1990 Effect of temperature and rentention time on methane recovery from water hyacinth-cowdung. *J. Ferment. Bioeng* 70: 340-342

Marique PhD, Gilles A, Edeline F and Joassin L 1989 Thermophilic semisolid anaerobic digestion of municipal refuses. *Biotechnol. Bioeng.* 33:536-541

Mathrani IM, Johansen K and Ahring BK 1994 *Experiences with thermophilic anaerobic digestion of manure, organic industrial and household waste at the large scale biogas plant in Vegger, Denmark.* Proceedings of the seventh international symposium on anaerobic digestion, Cape Town, South Africa. pp. 365-374

Op den Camp HJM, Verhagen JMF, Kivaisi AK, de Windt FE, Lubberding HJ, Gijzen HJ and Vogels GD 1988 Effects of lignin on the anaerobic degradation of (ligno) cellulose wastes by rumen microorganisms. *Appl. Microbiol. Biotechnol.* 29:408-412

Owens JM and Chynoweth DP 1993 Biochemical methane potential of municipal solid waste (MSW) components. *Wat. Sci. Tech.* 27: 1-14

Pavlostathis SG and Giraldo-Gomez E 1991 Kinetics of anaerobic treatment: A critical review. *Critical Reviews in Environmental Control* 21: 411-490

Rivard CJ, Vinzant TB, Adney WS, Grohmann K and Himmel ME 1990 Anaerobic digestibility of two processed municipal solid waste materials. *Biomass* 23:201-214

Teunissen MJ, Marras AES, Op den Camp HJM and Vogels GD 1989 Improved methods for simultaneous determination of alcohols, volatile fatty acids, lactic acid or 2,3-butanediol in biological samples. *Microbiological Methods 1*0: 247-254

Wang CN and Jeris JS 1976 Biochemical mechanisms in the methane fermentation of glutamic and oleic acids. *Wat. Res.* 10:9-11