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VOLATILE FATTY ACIDS GENERATED DURING ANAEROBIC TREATMENT OF SEWAGE SLUDGE

M.H. MOSTAFA, A.A. AMER AND M.A. BADAWI

Agricultural Microbiology Res. Dept. Soil, water and Environment Research Institute, Agricultural Research Centre, Giza, Egypt.

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Abstract

Generation of volatile fatty acids (VFAs) during anaerobic digestion of sludge have higher commercial value than methane produced subsequently. Therefore, it was decided to study conditions, e.g. pH and temperature, necessary to maximize production of VFA, concentrations of individual fatty acids were measured.

Total volatile fatty acids production of the treated sewage sludge was increased with the depth of the acid phase reactor. In a reactor of 100 cm depth and 30 cm width, volatile fatty acids increased from 37.1 meq/L at the first port (15 cm from top) to 78.8 meq/L at the fourth port (center of the reactor 60 cm from top). Moving toward bottom or top of the reactor decreased total fatty acids content, and then decreased to reach 45.8 meq/L at the seventh port (lower port). Studying the volatile fatty acid fractions using gas chromatography techniques showed that the volatile fatty acids fractions were acetic, propionic, isobuteric, buteric and caproic acids. The quantity of the volatile fatty acid fractions concentration followed the aforementioned sequence. The highest content of the volatile fatty acids fractions were recorded in the samples withdrawn from port No. 4 (middle of the reactor), while the lowest quantities recorded toward the top and the bottom of the reactor. Favorable pH values were around 6 and below 7.

INTRODUCTION

Anaerobic digestion is essentially hydrolysis, acidification (first phase) and gasification (second phase) of the soluble organic compounds. The two phases are very different in terms of physiology, nutritional requirements, growth kinetic capabilities, and sensitivity to environmental stresses (Pohland and Ghosh, 1971). By separating them into two vessels and controlling conditions within the two systems to meet the needs of the microorganisms, higher growth rates can be attained (Wilson, 1981 and Badawi *et al.*, 1992), In the original two-phase digestion process, control of the rate of organic assimilation is limited to the first stage. Acid-forming bacteria are physically separated to provide optimum condition for each group, this increasing waste stabilization and methane production rates (Bruce, 1984).

In the first phase of two-phase digestion, the complex organic compounds such as fats, proteins and carbohydrates are hydrolysed, fermented and biologically assimilated by facultative and obligate anaerobic bacteria, and for the most part, the end products of the conversion are organic fatty acids. Acid froming bacteria carry out these initial conversion to obtain the small amounts of energy released for growth, and a small portion of the organic waste is converted into cells. During the second phase, organic acids are converted by several different bacteria to gaseous end products, e.g. methane and carbon dioxide. Since the survival of the methane former is dependent on that of acid former, a strict balance between the two is essential for the success of the system (Wilson, 1981).

The rates of hydrolysis and acidogenic reactions are higher than the methane formation rates (Ghosh *et al.*, 1975). Therefore the volatile fatty acids can be accumulated and have an inhibitory effect on the methane forming bacteria if the equilibrium between these stages are not realized (Kroeker *et al.*, 1979). The environmental conditions that favour the acid forming process does not favor the methane formation. Therefore, the two phase fermentation process is considered the best solution to maximize the biological activity in every stage.

The objective of this study is to maximize the bioconversion of sludge volatile solids to produce volatile fatty acids, e.g. acetic and propionic, which can be used for agricultural and industrial purposes.

MATERIALS AND METHODS

Sewage sludge was obtained from Abu-Rawash sewage plant, Giza Governorate. It was collected before air beds at the final treatment to produce poudrette. The chemical composition of the sewage sludge is presented in Table 1.

The study of the acid phase included the performance of acid reactor, the quantitative and qualitative productivity of organic acids and their accumulation in relation to the reactor depth. Changes of pH value along the reactor depth were followed.

To carry out this experiment a 40 liter reactor was filled with diluted sewage sludge, e.g. 4%. The reactor is illustrated in Fig. 1 The reactor containd a cylindrical column, 100 cm in height and 30 cm in width, of 40 litter capacity. The reactor was requiped with 7 sampling ports every 15 cm and has a manual stirrer. The manual stirrer was used twice daily after sampling for mixing the materials. Semicontinuous fermentation was carried out for 3 cycles, each cycle continued for 15 days. Data are presented as an average of each cycle. The hydraulic retention time (Amer, 1993) was followed at 5 days when treating the Egyptian sewage sludge an-

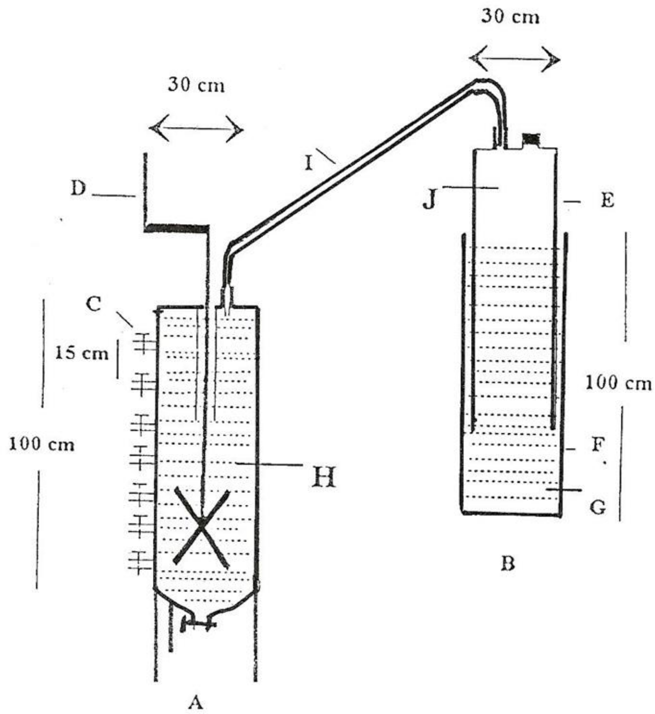

Fig. 1. Biogas reactor and gas holder

A-Reactor
B- Movable gas holder
C- Sampling ports
D- Stirrer
E- Movable part
F- Stable part
G- Acidified water
H- Sewage sludge materials
I- Polyethylene tubes
J- Biogas

aerobically. Samples were taken from the different ports level to evaluate total volatile fatty acids (VFAs) production and the individual concentration according to Neish (1952). Individual volatile organic acids were subjected to analysis using Gow-Mac series 750 GLC technique as described by Walter and William (1980). pH values were determined in different ports of the acid phase reactor using glass electrode pH meter.

Table 1. Chemical analysis of raw sludge used.

Parameter	Value	Parameter	Value
Total soilds (%)	4.130	C/N ratio	16.800
Total nitrogen (%)	2.200	pH	6.3
Total phosphorus (%)	0.528	EC (dS m^{-1})	2.5
Total potassium (%)	0.274	NH_3 (ppm)	217.5
Organic matter (%)	63.750	VFA (meq/L)	25.3
Organic carbon (%)	36.970		

RESULTS AND DISCUSSION

A. pH values

Table 2 illustrates the detected pH values in the different ports level of the reactor. It was clear from Fig. 2 that the average pH values ranged between 5.22 and 6.74 units during acid phase digestion of the sewage sludge all over the course of the fermentation period. pH values decreased with depth till the fourth port, then increased again to the lowest port No. 7. The figure showed that the middle port of the acid phase reactor gave the highest concentration of acids build up in the reactor. This indicates that the increase in acidity coincided with the increase in volatile fatty acids production (Jhones and Szekely, 1986 and Badawi *et al.*, 1992).

Table 2. pH changes at different ports level in the acid phase fermentation of sewage sludge.

Port No.	Cycle No.			
	1st	2nd	3rd	Average
1	6.84	6.66	6.71	6.74
2	6.63	6.48	6.44	6.52
3	5.58	5.50	5.64	5.57
4	5.23	5.30	4.90	5.22
5	6.58	6.31	6.35	6.41
6	6.56	6.50	6.45	6.53
7	6.63	6.73	6.81	6.72

B. Total volatile fatty acids (TVFAs) production

The total volatile fatty acids produced during the acid phase fermentation are presented in Table 3 and Fig. 2. The profile of the produced acids showed that it increased with depth to reach its maximum concentration (74.8 meq/L) at the fourth port (middle of the reactor) and decreased gradually with depth to reach 45.8 meq/L. The acids production was undertaken for three cycles at 5 day HRT. The reactor showed steady state production thoughout the fermentation course, the peak value of acids production ranged between 68.8 to 78.9 meq/L. Similar results had been recorded by Ghosh *et al.* (1975) Kroeker *et al.* (1979), and Badawi *et al.* 1992).

Table 3. Total volatile fatty acids (meq/L) at the different ports level in the acid phase fermentation at (5 days HRT) 3 cycles of sewage sludge.

Port No.	Cycle No.			
	1st	2nd	3rd	Average
1	29.4	37.7	44.2	37.1
2	46.0	47.0	45.8	46.3
3	58.6	55.7	61.9	58.7
4	78.9	68.8	76.6	74.8
5	52.9	53.3	50.6	52.3
6	48.7	47.2	48.9	48.3
7	46.3	44.2	46.9	45.8

C: Fractionation of volatile fatty acids

Fig. 3 represents that the values of volatile fatty acids fractions during the three cycles of fermentation time. The results given in Table 5 reveal that acetic acid was the dominant and gave the highest concentration. Also, the highest concentration of acetic acid was in the middle port of the reactor (Port No. 4). Average value was 27.1 meq/L and ranged between 24.4 to 32.1 meq/L. Propionic, isobutyric, butyric and caproic acids were present in concentrations below that level of acetic acid concentrations. Propionic concentration ranged between 21.3 to 24.9 meq/L during the three cycles. Isobutyric acid ranged between 12.9 to 15.2 meq/L, while butyric acid was in the range of 4.9 to 5.9 meq/L. Caproic acid was of as the to least concentration and ranged between 4.1 to 4.7 meq/L.

For all individual volatile fatty acids detected, the middle port of the reactor showed the highest concentration for the acids production which might be the source of acids for feeding another methane reactor (Van den Berg and Lentz, 1980 and Van den berg and Kenndy,1981) Also the lower ports showed higher concentrations than

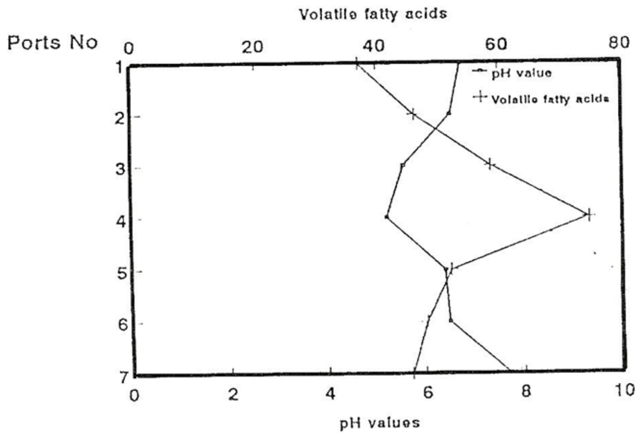

Fig. 2. Changes in pH and volatile fatty acids during acid phase of sewage sludge.

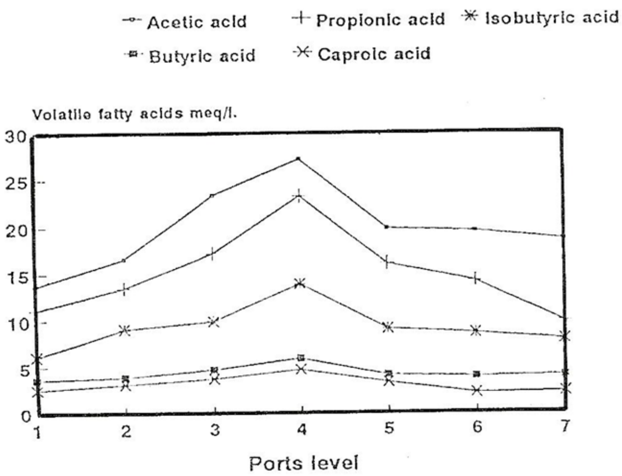

Fig. 3. Concentration of volatile fatty acids fractions during acid phase of sewage slugde.

the upper ones and this may be due to the heavy growth of the acid forming bacteria in the sediment layer.

D. Sludge effluent stability

Measurements of the U.S. Environmental Protection Agency (1979) regulations in the USA, specify criteria for adequate digestion based on the fraction expresses as a percentage of sludge volatile solids destroyed during digestion process.

Determination of sludge total solids (TS) and volatile solids (VS) expressed as g/100g (%) wet sludge (W/W) is a standard routine procedure at most works. For sludges which are anaerobically or aerobically digested, the ratio VS/TS is usually reduced from about 0.75 in the raw sludge to about 0.60 in the well-digested owing to the destruction of organic matter. It is possible to establish a normal range of VS/TS for the digested sludge above which there is a probability of the incomplete digestion and poor stability.

Table 4. Stability level for sewage sludge effluent during anaerobic digestion in different ports level of the reactor.

Port No.	Volatile solids (VS)	Total solids (TS)	Stability (VS/TS)
1	4.27	5.06	0.84
2	3.93	4.99	0.79
3	2.88	4.33	0.67
4	1.02	1.68	0.61
5	1.40	1.86	0.75
6	4.24	5.36	0.79
7	6.92	6.82	1.01

As shown in Table 4 the ratio VS/TS in this experiment showed good stability and digestibility specially in the middle port. Values ranged between 0.61 and 1.01 and gave 0.61 for the middle port which is considered in the range recommended by U.S. Envirmmental Protection Agency (1979).

The configuration of the anaerobic acid phase reactor is now fully understood. The distribution of the effluent has special shape, forming layers due to the physical separation. The upper layer is mainly scum and the bottom layer is also sediments. Both upper layer and the sediments are poor in volatile fatty acids. While the middle layer is rich in volatile fatty acids and considered the best place to withdraw the effluent to be processed for obtaining these acids.

From the results many of conclusions could be drawn. Concentration of VFA in the reactor was higher in the middle of the reactor and decreased toward the top and the bottom ports, for total and individual fatty acids. pH suitable for VFA production was around 6 and less than 7. Acidity and VFA production were parallel. The most suitable hydraulic retention time for increasing production of VFA from the Egyptian sewage sludge could be 5 days. Individual fractions of volatile fatty acids could be used in agriculture or industrial purposes, (Badawi *et al.*, 1992).

Table 5. Average contents of volatile fatty acids (meq/L) fractions during acid phase fermentation at different ports level.

Cycle No.	VFA fractions	Cycle in days						
		1	2	3	4	5	6	7
I	Acetic acid	11.5	18.1	22.2	32.1	20.6	20.7	20.8
	Propionic acid	8.6	12.8	16.9	24.9	16.4	16.1	15.7
	Isobutyric acid	5.2	8.6	11.4	12.9	9.2	7.9	7.2
	Butyric acid	2.2	3.6	4.5	4.9	3.8	2.3	1.6
	Caproic acid	1.9	2.9	3.6	4.1	2.9	1.7	1.0
II	Acetic acid	14.2	15.9	24.3	24.7	21.9	21.7	19.7
	Propionic acid	11.2	13.5	15.5	21.3	16.2	11.3	9.6
	Isobutyric acid	6.1	10.0	7.3	13.5	8.9	8.2	7.3
	Butyric acid	3.9	4.2	5.0	5.2	3.7	4.6	5.5
	Caproic acid	2.3	3.4	3.6	4.1	3.1	1.4	2.1
III	Acetic acid	15.4	15.9	23.5	24.4	17.1	16.2	15.3
	Propionic acid	13.6	14.2	19.1	23.5	15.6	15.1	14.1
	Isobutyric acid	7.1	8.7	10.9	15.2	9.4	9.6	9.1
	Butyric acid	4.7	3.9	4.6	7.5	4.7	4.7	4.9
	Caproic acid	3.4	3.1	3.8	6.0	3.8	3.3	3.5
Average	Acetic acid	13.7	16.6	23.3	27.1	19.8	19.5	18.6
	Propionic acid	11.1	13.5	17.2	23.2	16.1	14.2	9.8
	Isobutyric acid	6.1	9.1	9.9	13.9	9.1	8.6	7.9
	Butyric acid	3.6	3.9	4.7	5.9	4.1	3.9	4.0
	Caproic acid	2.5	3.1	3.7	4.7	3.3	2.1	2.2

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الأحماض العضوية المتطايرة المتولدة خلال المعالجة اللاهوائية لحمأة المجاري

محمود حلمي مصطفي - علي الدين أحمد عامر - محمد علي بدوي

قسم بحوث الميكروبيولوجيا الزراعية - معهد بحوث الأراضي والمياه والبيئة - مركز البحوث الزراعية.

أن عملية انتاج الأحماض العضوية اثناء عملية التخمر اللاهوائي لحمأه المجاري لها قيمة تجارية أكبر مما لو أستخدمت حمأه المجاري لانتاج غاز الميثان ولذلك فانه روعي في هذا البحث ضبط الظروف البيئية المناسبة من ضبط لدرجة الحرارة ورقم الحموضة اثناء عملية التخمر لتعظيم الانتاج من هذه الأحماض وقد تم قياس تركيز الأحماض العضوية الكلية وكذلك الفردية ووجد أن إنتاج الأحماض العضوية المتطايرة كان أقصي تركيز له عندما كان رقم الحموضة اقل من ٧ وحول رقم ٦.

وفي مخمر بارتفاع ١٠٠ سم وقطر ٣٠ سم وجد ان الأحماض العضوية تتزايد علي طول المخمر وخصوصا في المنطقة الوسيطة للمخمر (الفتحة رقم ٤ علي بعد ٦٠ سم من أعلي). وقد تراوح تركيز الأحماض العضوية بين ١,٣٧ ملليمكافيء /لتر عند قمة المخمر (فتحة رقم ١ علي بعد ١٥ سم من أعلي) وزاد التركيز حتي وصل إلي ٧٨,٨ ملليمكافيء/ لتر في منتصف المخمر. وقد لوحظ انه يقل التركيز عند قمة المخمر وكذلك عند القاع بينما يزداد التركيز في المنطقة الرائقة بوسط المخمر.

كذلك فانه عند فصل مكونات الأحماض العضوية المتطايرة لوحظ أن حمض الخليك كان هو الأكثر تركيزا علي طول محور المخمر وفي جميع الطبقات وكان التركيز الأعلي للاحماض في الطبقة الوسيطة علي طول المخمر.