Pergamon

Wat. Sci. Tech. Vol. 40, No. 1, pp. 223–229, 1999

0273–1223/99 $20.00 + 0.00

PII: S0273-1223(99)00388-1

THE DEVELOPMENT OF BIOLOGICAL METHODS FOR UTILISATION AND TREATMENT OF DILUTED MANURE STREAMS

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ABSTRACT

One possible solution for sustainable utilisation and treatment of diluted manure streams is preliminary separation of the solid and liquid fractions followed by separate biological treatment of both fractions. This approach was the starting point of a joint Russian-Dutch project: "The Development of Biotechnological Methods for Utilisation and Treatment of Diluted Manure Streams" (1996-1998). This paper describes the most important results of the project. The UASB process was found to be suitable for the pre-treatment of the liquid fraction of various types of manure using a lab-scale experimental set-up. The maximum organic loading rate (OLR) applied was approximately 12 g COD/l/day for hen or pig manure and 6 g COD/l/day for cattle manure using a hydraulic retention time (HRT) of about 1 day. The total COD reduction under these conditions was about 75% for the hen or pig manure and 42% for the cattle manure. The effluents obtained in this step can be used as liquid fertilisers (if possible) or should be post-treated to meet standards for discharge or reuse. Intensive composting can efficiently treat the solid manure fraction. Experiments at a pilot scale level with the solid fraction of hen manure showed that various amendments (peat, straw, sawdust) could be used for the production of composts having an elevated NPK content, reduced levels of *Clostridia* and faecal coliforms, vital weed seeds and the absence of *Salmonella* and helminth eggs.

KEYWORDS

Composting; fertiliser; manure; pre-treatment; UASB reactor.

INTRODUCTION

The yearly production of manure by centralised farms in Russia is more than 700 million tonnes (Table 1). A significant part of that manure (133 million tonnes) is generated at huge complexes (i.e. farms with yearly production upwards of 1 000 000 chickens, 216 000 pigs, or 15 000 cows). This manure contains only 1-4% total solids (TS) due to run-off procedures used for cleaning. These complexes are equipped with aerobic treatment plants, but their 30 years exploitation has demonstrated the complete failure of this technological approach. Often the aerobic systems work unsatisfactorily due to frequent overloading with manure, and therefore, these farms are responsible for the severe pollution of soils, ground waters, rivers and lakes in the surrounding areas. Also, such discharges lead to the loss of manure and its fertiliser potential. This is a tragedy considering the lack of organic fertiliser in Russia and the exhaustion of soils in most regions.

Table 1. Yearly manure production in Russian centralised farms

Type of manure	TS, %	Quantity, million tones/year
Litter cattle manure	13-15	432
Semi-liquid cattle manure	8-10	39
Liquid cattle manure	4-5	36
Semi-liquid poultry manure	8-10	67
Liquid pig manure	4-5	80
Very liquid pig manure	1-2	46
Total		700
Solid fraction which can be obtained from diluted cattle, pig and poultry manure	15-17	29
Manure wastewater	1-4	133

A possible solution for sustainable utilisation and treatment of diluted manure streams is the preliminary separation of the solid and liquid fractions by decanting or by using special equipment (separators, centrifuges) followed by separate biological treatment of both fractions (Fig. 1). For the solid phase, two options exist: anaerobic treatment or composting (aerobic). The latter is more appropriate from a practical point of view because dry and hygienic fertiliser can be obtained directly from the process. The liquid phase has to be treated before the water can be used or discharged. As a sole aerobic step is ineffective for complete treatment, the implementation of an anaerobic pre-treatment step using modern high-rate reactors can be a solution to the problem. Anaerobic effluent can be used as liquid fertiliser (if suitable) or post-treated using aerobic tanks which are already available.

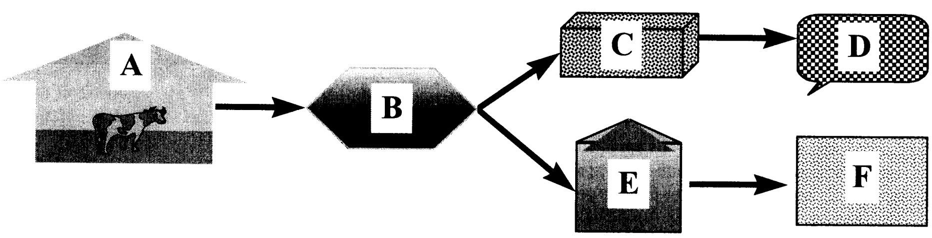

Figure 1. Proposed scheme for liquid manure treatment: A - farm (manure production); B - separation of solids/liquid; C - composting of solid fraction; D - fertiliser; E - anaerobic pre-treatment; F - post-treatment of liquid fraction.

The concept described above was taken as the basis of a joint Russian-Dutch project "The Development of Biotechnological Methods for Manure Treatment Focused on Fertiliser Production" (grant N299971 financed by The Netherlands Organisation for Scientific Research). This paper will present some research results obtained during the execution of this project, which was carried out from 1996 to 1998. Special emphasis will be placed on the following topics:

1. The examination of the suitability of the upflow anaerobic sludge blanket (UASB) reactor for the pre-treatment of liquid fractions of various types (hen, pig and cattle) of manure in terms of its treatment efficiency and methane production;

2. The optimisation of fertiliser production from the solid manure fraction using intensive composting at a pilot installation.

MATERIALS AND METHODS

UASB reactors. Investigations were carried out in laboratory UASB reactors (diameter - 6.8 cm, height - 85 cm, total working volume - 2.6 l) made from transparent plastic and equipped with 6 sampling ports along the reactor height. Operating temperature was 35°C. No recycling or mixing facilities were provided for the reactors, which were fed by peristaltic pumps "NP-1M" (Kievpribor, USSR). During reactor feeding, the feed wastewater flask was continuously agitated to prevent sedimentation of suspended solids (SS).

Manure wastewater. The liquid fraction of hen manure was taken directly from the upper part of the sedimentation reservoir of the industrial farm "Oktyabr'skaya" located in the Moscow region. The liquid fractions of pig and cattle manure were prepared by diluting the semi-liquid wastes from the pig and cattle farms of the enterprise "Serp i Molot" (the Moscow region) with tap water (1:2-10) then settling the SS in a sedimentation column for 12 hours. The supernatants were used as feeding influents. To partially pre-acidify the wastewater, the feeding flask was kept open at laboratory ambient temperature (18-20°C) for 1-2 days (micro-aerobic pre-acidification). The three feeding influents had the following characteristics (Table 2).

Table 2. Main characteristics of the feeding influents

Wastewater	COD_{tot}, g/l	COD_{cent}, g/l	TS, g/l	VS, g/l	TSS, g/l	VSS, g/l	pH	VFA, g COD/l
Hen manure	11-20	8-13	9-16	8-15	2-5	2-3	6.2-7.1	3.9-6.7
Pig manure	8-20	7-17	7-16	6-15	0-2	0-1	6.8-7.6	1.0-5.0
Cattle manure	5-8	4-6	4-7	4-6	0-1	0-1	6.6-7.5	0.2-0.5

Seed sludge and schedule of UASB runs. Two reactors (A and B) were initially seeded with 800 ml (approximately 35 g volatile suspended solids (VSS)) of mainly granular sludge, originating from an UASB reactor treating synthetic (glucose-acetate) wastewater (Kalyuzhnyi *et al.*, 1996). Both reactors were fed the liquid fraction of the hen manure (Run 1, duration - 4 months). After termination of the experiments with hen manure wastewater, reactor A with the sludge inside was stored without feeding at 4-8°C for 5 months before it was used for the treatment of the liquid fraction of pig manure (Run 2, duration - 3 months). When this run was finished, reactor A was again kept in a cool room without feeding or sludge removal for 3 months. This reactor was then used for experiments with the liquid fraction of cattle manure (Run 3, duration - 2.5 months).

Compost reactor. The batch compost reactor was a metal cylindrical horizontal tank (volume - 10 m^3) supplemented by chink floor in the bottom as well as temperature and O_2-meters. Forced aeration was carried out by an automatically controlled ventilator (productivity - 2000 m^3/hour) working in a programmed intermittent regime.

Composting mixture. The solid fraction of hen manure (SFHM) supplemented with various amendments (straw, peat, and sawdust) was used during the composting trials. Some characteristics of the ingredients used for preparation of composting mixtures are given in the Table 3.

Table 3. Some characteristics of the ingredients used for preparation of composting mixtures

Characteristics	Liquid hen manure	SFHM	Straw	Peat	Sawdust
TS, %	4-5	13-18	73-80	50-53	73-75
VS, %	3.4-4.0	10.8-14.0	72-79	ND	ND
N_{tot}, %	0.26-0.3	0.13-0.15	0.5-0.51	ND	ND
P_2O_5, %	0.3-0.35	0.42-0.45	0.25-0.26	ND	ND
K_2O, %	0.21-0.22	0.13-0.14	0.9-0.91	ND	ND
NPK, kg/ton	7.7-8.7	6.8-7.4	16.5-16.8	ND	ND

ND -not determined

Analysis. Total gas production/consumption was recorded by a gas meter "GSB-400" (Gaspribor, USSR). All gas measurements are expressed at 0°C and standard pressure (760 mm Hg). Feed input to the UASB reactors was monitored by measuring the accumulated outflow on a daily basis. Gas composition and volatile fatty acids (VFA) were analysed by gas chromatography (Kalyuzhnyi *et al.*, 1996). Determinations of specific sludge activities and the preliminary treatment of sludge samples for electron scanning microscopy were performed as described previously (Kalyuzhnyi *et al.*, 1996). The preparations were observed using an ISM-1300 microscope (Jeol, Japan). All other analyses were performed using Standard Methods (APHA, 1985). Agrochemical, microbiological and hygienic characteristics of the composts obtained were analysed according to Russian norms (Agroprom, 1989).

RESULTS AND DISCUSSION

UASB pre-treatment of liquid fractions of various types of manure

Though the seed sludge had been stored unfed for a period of one year before these experiments, it quickly adapted to a new feeding substrate - hen manure wastewater. After 1 month, both reactors were running almost as replicates. Each had reached an organic loading rate (OLR) of 9 g COD/l/day and total COD reduction of more than 75% (Kalyuzhnyi *et al.*, 1998). Thereafter, a variety of different experimental conditions with regard to influent waste strengths (11-20 g COD/l), hydraulic retention times, HRT (0.9-3.6 days), and OLR (5.5-12.1 g COD/l/day) were imposed on the reactors to investigate their steady-state performance. The data in Table 4 show that the both UASB reactors demonstrated satisfactory performance for the pre-treatment of the high strength liquid fraction of hen manure up to an OLR of approximately 12 g COD/l/day. At these OLR and HRT, both reactors were stable with total COD reduction of 70-75% and a biogas production rate of 3.5-3.6 l/l/day (methane content - 79-81%). Summarising the results obtained under steady-state conditions, one can conclude for the investigated system that the total COD reduction decreased slightly with a decrease of HRT as well as with a decrease of influent waste strength (Kalyuzhnyi *et al.*, 1998). Such weak dependence of total COD reduction on both the factors mentioned above can be explained by the formation of a balanced microbial community inside the reactor efficiently converting the easily biodegradable part of the influent COD into biogas under investigated range of HRT and influent waste strength.

During start-up of reactor A on the liquid fraction of pig manure, an OLR of 1.5 g COD/l/day was used. A gradual increase in the OLR (over 2 months) led to the development of a stable pre-treatment process with an OLR of more than 12 g COD/l/day and total COD reduction of more than 75% (Table 4). A negligible level of VFA in the effluent throughout the run suggested almost complete mineralisation of the biodegradable influent COD. It should be noted, however, that such exhaustion of the easily degradable COD might create problems during biological post-treatment (e.g., for N and P removal).

Table 4. Steady-state operation performance of UASB reactors treating manure wastewater*

Parameters	Hen manure (run 1) Reactor A	reactor B	Pig manure (run 2)	Cattle manure (run 3)
Maximal OLR applied, g COD/l/d	12.07	11.05	12.39	6.63
HRT, days	0.87	1.81	1.19	1.08
Influent COD_{tot}, g/l	10.5	18.0	14.7	7.16
Effluent COD_{tot},g/l	2.8±0.3	4.5±0.3	3.4±0.2	4.2±0.1
Reduction on COD_{tot}, %	73.3±2.6	75.0±1.8	77.0±1.3	41.5±1.8
Gas production, l/l reactor/day	3.59±0.31	3.51±0.28	4.14±0.26	0.81±0.06
CH_4 in biogas, %	79±1	81±1	77±1	86±2
Effluent pH	7.9±0.1	8.1±0.1	7.5±0.1	7.5±0.1
Total effluent VFA, g COD/l	0.40±0.03	1.05±0.07	0.02±0.01	0.01±0.01

*Results expressed as means ± standard errors (n=3)

The change in reactor A to the more recalcitrant liquid fraction of cattle manure did not result in any noticeable difficulties in operation stability. The total COD reduction decreased substantially (Table 4), but excessive foaming and sludge flotation which often occur with such wastewater, were not observed. The decrease in total COD reduction is related to the significant presence of hardly biodegradable COD (e.g., humic acids) in cattle manure wastewater. The methane yield (0.25 l/g COD removed) was somewhat lower than theoretically expected (0.35 1/g COD consumed). This discrepancy is mainly attributed to entrapment of undigested SS and colloidal substances in the reactor because the entrapped brown aggregates were visible in the sludge bed zone. However, their presence apparently did not influence the overall reactor performance.

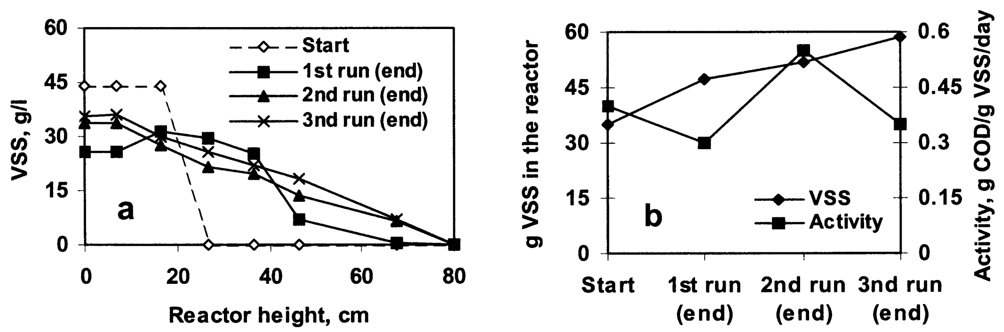

Figure 2. Characterisation of the sludge from the reactor A in various runs: a - VSS profile; b - total VSS in the reactor and specific aceticlastic activity of the sludge bed.

At the end of each run, the sludge from reactor A was characterised in terms of its VSS profile and specific aceticlastic activity (Fig. 2). The overall quantity of VSS in the reactor (Fig. 2b) as well as the height of the sludge bed (Fig. 2a) increased throughout the experiments. However, the VSS concentration in the sludge bed dropped significantly during run 1 resulting in deterioration in the quality of the granular sludge. Following run 1, the VSS marginally increased (run 2 and 3) but remained lower than in the seed sludge (Fig. 2a). Electron microscopic examination of sludge samples taken at the end of run 1 showed a significant presence of irregularly formed aggregates, appearing to be segments of decomposed granules (Kalyuzhnyi *et al.*, 1998). Moreover, the sludge became almost completely flocculent by the end of run 2. It is likely that such wastes (i.e., liquid fractions of manure) have a negative influence on the stability of granules because of a significant presence of proteinaceous and colloidal substances. The specific aceticlastic activity in the sludge bed (Fig. 2a) oscillated throughout the runs. The activity dropped during the first run (due to dilution of the reactor sludge by entrapped waste VSS), then increased under feeding with pig manure wastewater (apparently due to a lower VSS concentration in this influent as compared to the liquid fraction of hen manure, Table 2), then again decreased after switching to cattle manure wastewater (apparently due to entrapment of hardly digested colloidal matter to the sludge). Thus, although the sludge became flocculent during the runs, the reactor was able to cope with the low HRT (around 1 day) and accomplished almost complete elimination of the easily biodegradable COD (only traces of VFA were detected during the runs 2 and 3).

Composting

The major objective of this research was to develop an intensive composting process producing an agriculturally useful and hygienically safe product at a reasonable price. Optimisation of the composting process was made with regard to the following environmental parameters - initial moisture content of composting mixture, aeration regime, duration of treatment, and type of amendment. The evaluation criteria for the product obtained were fertiliser potential, safety and economic expenses.

The optimal initial moisture content of the composting mixture was found to be 65-70%. Higher moisture content led to the increased formation of anaerobic zones inside the composting body and slowed the composting process. Lower moisture content caused mass-transfer limitations for the microorganisms, substrates and nutrients involved which led to a decrease in composting efficiency.

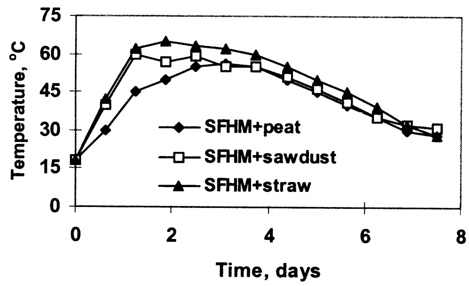

Figure 3. Temperature during intensive composting of SFHM with various amendments (experimental conditions are given in the Table 5).

Based on economic considerations, intermittent forced aeration was implemented. After some theoretical calculations and a number of practical trials, it was concluded that a compost with a reasonable maturity could be obtained after 8 days treatment with an intermittent aerator working as follows: 1 min. - "on"; 8 min. - "off". In this way, a temperature of approximately 60°C (Fig. 3) for stabilisation and sanitation of the composting mixture could be ensured. The corresponding results obtained under such conditions for 3 different amendments are presented in Table 5. It can be seen that using straw required less volume of amendment and gave a drier product, but the treated compost had the least nitrogen content as compared to the other amendments. The lower nitrogen content was probably due to the elevated losses of ammonia under applied aeration regimes. In general, the NPK content of the composts was 2-3 times higher (Table 5) than that of both the untreated SFHM and the farm-produced liquid hen manure (Table 3). All the composts obtained had a brown colour, crumb-like structure and were almost odourless.

Table 5. Some characteristics of the composts obtained from the SFHM (moisture - 82%)*

Amendment (% moisture)	Ratio of SFHM:amendment	Ready compost				
		TS, %	N_{tot}, %	P_2O_5, %	K_2O, %	NPK, kg/ton
Peat (50)	1 : 1.13	46.4	0.97	0.36	0.23	15.6
Sawdust (25)	1 : 0.43	47.8	1.20	0.53	0.39	21.2
Straw (20)	1 : 0.38	55.6	0.89	0.54	0.54	19.7

*Composting time of 8 days, intermittent aeration rate (206 m^3/ton composting mixture)

The microbiological and hygienic characteristics of the fertilisers obtained were thoroughly studied for the straw amended composts (Table 6). It can be seen that the composting process resulted in complete elimination of *Salmonella* and helminth eggs as well as a 100-fold reduction in *Clostridia* and faecal coliforms (Table 6). Although the two latter species did not completely die-off during composting, their levels in the ready product did not exceed the Russian limits for land application of organomineral fertilisers derived from manure (Agroprom, 1989).

Table 6. Microbiological and hygienic characteristics of straw amended compost and hen manure

Material	Total microbial contamination, 10^4 cells/g	Faecal coliform, 10^4 cells/g	Clostridia, 10^4 cells/g	Salmonella	Helminth eggs
Farm-produced hen manure	100	1	>1	Present	Present
SFHM	15	0.1	0.1	Present	Present
Straw amended compost*	10	<0.01	<0.01	Absent	Absent
Limits for land application#	-	<0.01	<0.01	Absent	Absent

*Experimental conditions are the same as in the Table 5.
#Anonymous, 1989

Table 7. Content of weed seeds in straw amended compost and its ingredients (per 1 kg)

Material	Initial weed seeds, number/kg	Sprouted weed seeds, number/kg	% of sprouted weed seeds
Farm-produced hen manure	48	22	46
SFHM	30	12	40
Straw	24	10	42
Untreated SFHM:straw mixture	32	12	38
Straw amended compost*	31	3	10

*Experimental conditions are the same as in the Table 5.

From Table 7, it can be seen that all ingredients of the straw amended compost were moderately contaminated with vital weed seeds. However, the intensive composting led to their significant inactivation approximately in 4 times).

CONCLUSIONS AND FUTURE WORK

From the research presented in this paper, the following conclusions can be drawn.

1. The UASB process is suitable for the pre-treatment of the liquid fraction of various types of manure and has been demonstrated at lab-scale. The maximum OLR applied was approximately 12 g COD/l/day for hen and pig manure and 6 g COD/l/day for cattle manure operating with an HRT of about 1 day. The total COD reduction under these conditions was approximately 75% for hen and pig manure and 42% for cattle manure. Although the reactor sludge became flocculent during the course of the experiments, noticeable difficulties in the reactor performance like excessive foaming or sludge flotation were not observed. The effluents obtained in this step still contain relatively high COD concentrations (2-4 g/l) and are enriched with ammonia and phosphate. They can be used as liquid fertiliser if sufficient lands surround farms, but this is usually not the case for big animal complexes in Russia. In such situations, the anaerobic effluents must be post-treated (possibly using existing aeration tanks) to remove both BOD and nutrients (N,P) to meet standards for discharge or reuse. Future work will be focused in this direction.

2. An intensive composting process can efficiently treat the solid fraction of manure. Process optimisation at pilot-scale using SFHM showed that various amendments (peat, straw, sawdust) could be used for the production of fertilisers having an elevated NPK content as compared to both the farm producing liquid manure and its solid fraction. The composts obtained were free of *Salmonella* and helminth eggs and contained substantially reduced levels of *Clostridia* and faecal coliforms. The reduced levels do not exceed the Russian limits for land application of organomineral fertilisers derived from manure. It also should be noted that the application of intensive composting led to significant inactivation of vital weed seeds.

ACKNOWLEDGEMENT

The financial supports of The Netherlands Organisation for Scientific Research (grant N299971) are greatly appreciated. We also would like to thank Dr. John Copp for revision of the English.

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