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ANAEROBIC TREATMENT OF LIQUID FRACTION OF HEN MANURE IN UASB REACTORS

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Abstract
The anaerobic treatment of liquid fraction of hen manure was studied in two parallel laboratory 2·6 l UASB reactors at 35°C. The granular sludge from a laboratory UASB reactor treating synthetic wastewater was used as a seed sludge. The liquid fraction of hen manure was obtained directly from an industrial farm located in Moscow region after separation of diluted manure in situ into solid and liquid fractions. Before feeding, the waste water was preacidified under micro-aerobic conditions at laboratory ambient temperature (18–20°C) for 1–2 days. The influent COD was 10·5–20 g/l of which volatile fatty acids (VFA) were 3·9–6·7 g COD/l, pH was between 6·2–7·1. The initial organic loading rate (OLR) was 1 g COD/l day^{-1}, then it was stepwise increased to the values of 11–12 g COD/l day^{-1}. Under these OLR and hydraulic retention time of 1–2 days, both reactors demonstrated optimal stability with treatment efficiencies on total COD reduction of 70–75%. The biogas production rate at the OLR of 11–12 g COD/l day^{-1} was 3·5–3·6 l/l day^{-1} (methane content — 79–81%) and effluent pH of about 8. © 1998 Published by Elsevier Science Ltd. All rights reserved

Key words: Hen manure, preacidification, sludge profile, treatment efficiency, UASB reactor.

INTRODUCTION

The insufficient treatment of manure is currently one of the most urgent environmental problems existing in Russia. Large pig farms (up to 216 000 pigs per year), beef-breeding complexes (up to 15 000 per year) and industrial poultry farms (up to 4 000 000 chickens per year) are characteristic of our country. The yearly production of manure on centralised farms in Russia exceeds 700 million m^3 (Table 1). A significant part of the manure produced (133 million m^3) contains only 2–4% total suspended solids (TSS) due to so called ‘hydraulic wash-out technologies’ used for cleaning. Farm based aerobic treatment plants work inefficiently due to frequent overloadings. The implementation of an anaerobic pre-treatment step can be a solution to the problem. A number of studies using different reactor configurations in the anaerobic digestion of cattle, swine and duck wastewaters have been reported (Van Velsen, 1979; Bolte *et al.*, 1985; Schomaker, 1987; Unguryanu, 1988; Zeeman *et al.*, 1988; Lo *et al.*, 1994). The objective of this study was to examine the suitability of the upflow anaerobic sludge blanket (UASB) reactor (Lettinga *et al.*, 1980) for the pre-treatment of the liquid fraction of hen manure in terms of its treatment efficiency (TE) on total COD reduction and methane production.

METHODS

Reactors

Investigations were carried out in two (A and B) laboratory UASB reactors (diameter — 10 cm, height — 85 cm, total working volume — 2·6 l) made from transparent plastic and equipped with six sampling ports along the reactor height. Operating temperature was 35°C. No recycling or mixing facilities were provided for both reactors, which were fed by peristaltic pumps ‘NP-1M’ (Kievpribor, USSR).

Table 1. Yearly manure production in Russian centralised farms (Kovalev, 1996)

Type of manure	Moisture, %	Volume, million m^3/year
Litter cattle manure	85–87	432
Semi-liquid cattle manure	90–92	39
Semi-liquid poultry manure	90–92	67
Solid fraction of cattle, pig and poultry manure	83–85	29
Manure wastewaters	96–98	133
Total	—	700

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Table 2. Main characteristics of the feeding influent

^{a}COD$_{tot}$ (g/l)	^{b}COD$_{cent}$ (g/l)	TS (g/l)	VS (g/l)	TSS (g/l)	VSS (g/l)	pH	VFA (g COD/l)
10·5–20	8–12·5	8·9–15·8	8·1–14·7	2·1–4·6	1·8–3·3	6·2–7·1	3·9–6·7

^{a}COD$_{tot}$ — total COD concentration.
^{b}COD$_{cent}$ — COD concentration after centrifugation.

During feeding of the reactors, the feed wastewater flask was continuously agitated to prevent sedimentation of suspended solids (SS).

Wastewater

The liquid fraction of hen manure was directly taken from the upper part of the sedimentation reservoir of the industrial farm 'Oktyabr'skaya' located in the Moscow region. To make a partial preacidification of waste water, the feeding flask was kept open at laboratory ambient temperature (18–20°C) during 1–2 days (microaerobic preacidification). Finally, the feeding influent had the following characteristics (Table 2).

Seed sludge

The reactors were 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).

Analysis

Total biogas production 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 was monitored by measuring the accumulated outflow on a daily basis. TS, TSS, VS, VSS and COD were determined using standard methods (APHA, 1985). Biogas composition and volatile fatty acids (VFA) were analysed by gas chromatography (Kalyuzhnyi *et al.*, 1996). The points shown in the graphs are the means of 2–4 measurements. Statistical analysis of data was performed by the program 'Descriptive statistics' (Microsoft Excel).

Determinations of specific sludge activities were performed in 120 ml glass bottles sealed with a rubber septum retained with a screw-cap. Each bottle contained 40 ml of mineral medium (Varfolomeyev and Kalyuzhnyi, 1989), sodium acetate (1·5 g/l) and a known amount of sludge VSS. At the start of each experiment the gas phase of the bottles was flushed with argon. The bottles were then placed in a thermostat at 35°C. All the activity tests were carried out in two replicates. The methane concentration of the head space of each bottle was monitored every 4–6 h. The specific sludge activities were calculated as described previously (Kalyuzhnyi *et al.*, 1996).

The preliminary treatment of sludge samples for electron scanning microscopy was performed as described previously (Kalyuzhnyi *et al.*, 1996). The preparations were observed using an ISM-1300 microscope (Jeol, Japan).

RESULTS AND DISCUSSION

Start-up

Since the seed sludge had been stored unfed for a period of one year before these experiments, the initial organic loading rate (OLR) was set to 1 g COD/l day^{-1}. The behaviour of both reactors, running almost as replicates during the start-up period, was similar therefore only the data for reactor A are presented (Fig. 1). It is seen that gradual decrease (during a month) of hydraulic retention time (HRT) under a fixed waste strength of 12 g COD/l led to the development of a stable treatment process with OLR of 9 g COD/l day^{-1} and treatment efficiency (TE)—higher than 75% [Fig. 1(a) and (b)]. Noticeable difficulties in the reactor performance like excessive foaming or sludge flotation were not observed at all. The biogas [Fig. 1(c)] and methane productions were comparable to the theoretically expected ones (1 g COD corresponds 0·35 l CH_4 under normal conditions) at the end of start-up period, while in the beginning, they were somewhat behind this level. This discrepancy can be mainly attributed to entrapment of the undigested part of SS of the waste in the reactor, because the entrapped brown aggregates were visually observed in the sludge-bed zone but their presence did not apparently influence the overall reactor performance. The effluent pH slightly oscillated above 8 [Fig. 1(d)] due to ammonia formation. VFA were almost absent in the effluent under the low OLR, though their concentration (especially acetate and propionate) increased after switching on the highest OLR applied during the start-up period [Fig. 1(d)]. Only traces of butyrate were detected at this stage of the experiments (data not shown). Methane content in the biogas produced was around 80% [Fig. 1(c)], due to carbon dioxide consumption by the reactor medium with relatively high pH [Fig. 1(d)].

Steady-state performance

The generalised results of the experiments carried out after the start-up period under steady-state conditions (i.e. when the operation regime was maintained for a minimum of at least three HRT and gas production rates were constant ±10%) are shown in Table 3 and Fig. 2. The waste strength was variable during these experiments because we tried to work under conditions close to the real situation at the poultry farm. The reactors did not run as replicates at this stage of experiments. In general, the data of Table 3 show that the both UASB reactors showed satisfactory efficiency for the pre-treatment of a high strength liquid fraction of hen manure up to the OLR of about 11–12 g COD/l day^{-1}. Under these OLR and HRT of 1–2 days, both reactors demonstrated optimal operation stability with a TE of 70–75%. Meantime the application of elevated OLR under the waste strength higher than 15 g COD/l (Table 3, reactor B) led to increased effluent COD concentrations (up to 4·5 g/l.) with significant presence of VFA (up to 1·4 g COD/l). The biogas production rate at the OLR of 11–12 g COD/l day^{-1} was 3·5–3·6 l/l day^{-1} (methane content 79–81%). Summarising the results obtained under steady-state conditions, one can conclude for the investigated system that the TE on the basis of total COD slightly decreased with a decrease of HRT [Fig. 2(a)] as well as with a decrease of influent waste strength [Fig. 2(b)]. Such weak dependence of TE on both the factors mentioned above can be explained by a formation of a balanced microbial community inside the reactor ensuring almost complete biogasification of the biodegradable part of influent COD under the investigated range of HRT and influent waste strength.

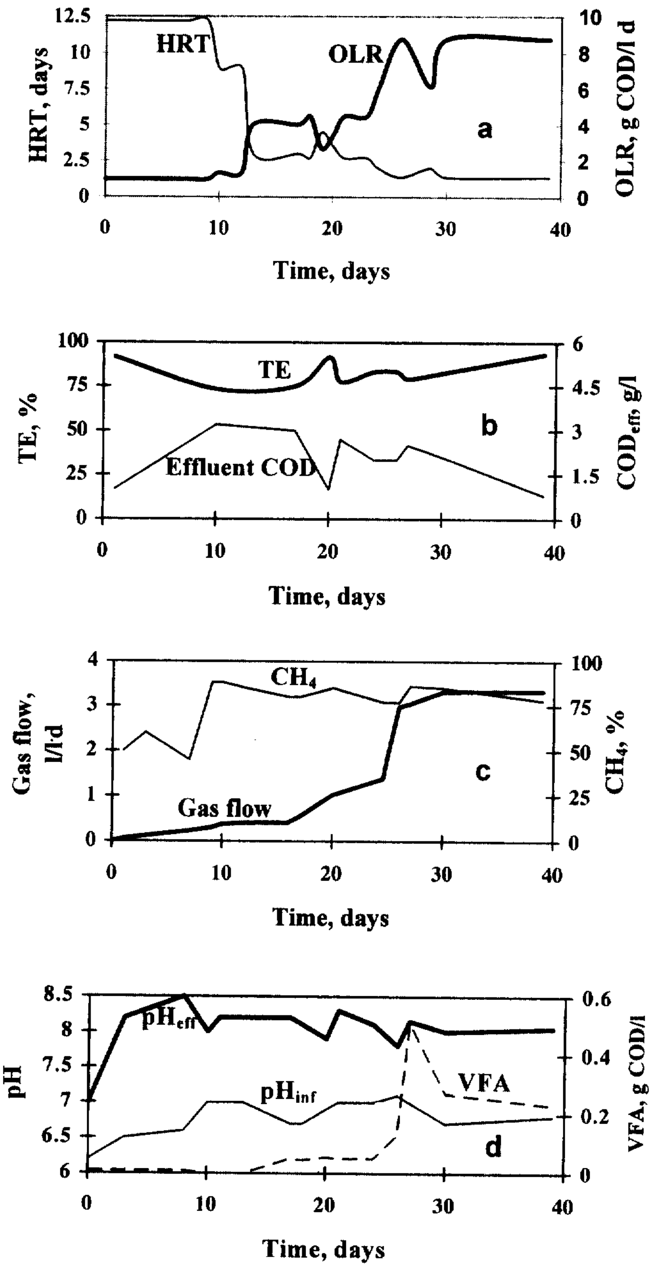

Fig. 1. Operation performance of reactor A treating the liquid fraction of hen manure during the start-up period (waste strength was 12 g COD/l).

At the end of steady-state experiments, the sludge from the reactors A was additionally characterised. The VSS concentration along the height of reactor is shown in Fig. 3. The total sludge quantity in the reactor was estimated as 100 g VSS, which exceeded the seeding sludge quantity by three times (as was mentioned above, some accumulation of undigested VSS of waste also took place). The average specific activity of the sludge was 0·3 g CH_4-COD/g VSS day^{-1}, which was somewhat less than the activity of seeding sludge (0·4 g CH_4-COD/g VSS day^{-1}), apparently due to dilution of the reactor sludge by entrapped waste VSS. The electron microscopic examination of sludge samples showed a significant presence of irregular form aggregates, appearing to be segments of decomposed granules (Fig. 4). It is likely that wastes such as the liquid fraction of hen manure have a negative influence on the stability of granules because of a significant presence of proteinaceous and colloidal substances (Lettinga and Hulshoff, 1992). Thus, though the sludge at the end of the experiments was mainly in a flocculent form, the reactor was able to cope with the elevated OLR (higher than 10 g COD/l day^{-1}) with satisfactory TE (around 75%).

CONCLUSIONS

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

The suitability of the UASB process for the pre-treatment of a liquid fraction of hen manure has been demonstrated up to the OLR of about 11–12 g COD/l day^{-1} and HRT of 1–2 days with the TE of 70–75% on the basis of total COD reduction, though the sludge at the end of the experiments was mainly in a flocculent form.

Noticeable difficulties in the reactor performance such as excessive foaming or sludge flotation were

Table 3. Steady-state operation performance of UASB-reactors treating liquid fraction of hen manure[a]

OLR (g COD/l day^{-1})	HRT (days)	Influent COD$_{tot}$ (g/l)	Effluent COD$_{tot}$ (g/l)	TE on COD$_{tot}$ (%)	Gas production (l/l day^{-1})	CH$_4$ (%)	pH	Total VFA (g COD/l)
ReactorA								
5·97	3·35	20·0	1·8±0·7	91·0±3·4	1·87±0·18	78±1	8·1±0·1	0·23±0·02
7·92	1·52	12·0	2·8±0·3	76·7±2·7	2·09±0·19	88±1	8·0±0·1	0·02±0·02
9·85	2·03	20·0	3·2±0·6	84·0±3·0	2·99±0·20	80±1	8·2±0·1	0·55±0·03
10·19	1·03	10·5	2·7±0·3	74·3±2·6	2·74±0·25	79±1	8·1±0·1	0·5±0·05
12·07	0·87	10·5	2·8±0·3	73·3±2·6	3·59±0·31	79±1	7·9±0·1	0·4±0·03
Reactor B								
5·52	3·62	20·0	4·5±0·4	77·5±1·8	1·83±0·10	82±1	8·1±0·1	0·8±0·05
6·63	1·58	10·5	3·5±0·3	66·7±1·6	1·99±0·19	78±1	8·3±0·1	0·69±0·06
7·78	2·06	16·0	4±0·3	75±1·7	2·18±0·20	82±1	8·0±0·1	1·43±0·05
11·05	1·81	18·0	4·5±0·3	75±1·8	3·51±0·28	81±1	8·1±0·1	1·05±0·07

[a]Results expressed as means ± standard errors ($n = 3$).

not found at all the OLR applied, in spite of an observed presence of colloidal substances in the influent.

Thus, the UASB pre-treatment of the liquid fraction of hen manure can be considered as a possible approach for a solution of the problem of proper treatment of 'hydraulic wash-out' manure streams. The effluents obtained in this step are believed to be post-treatable on the existing airtanks without overloading, due to a substantial reduction of the incoming COD concentration after anaerobic pre-treatment. To confirm the viability of a suggested approach for full-scale implementation, more targeted pilot experiments are needed.

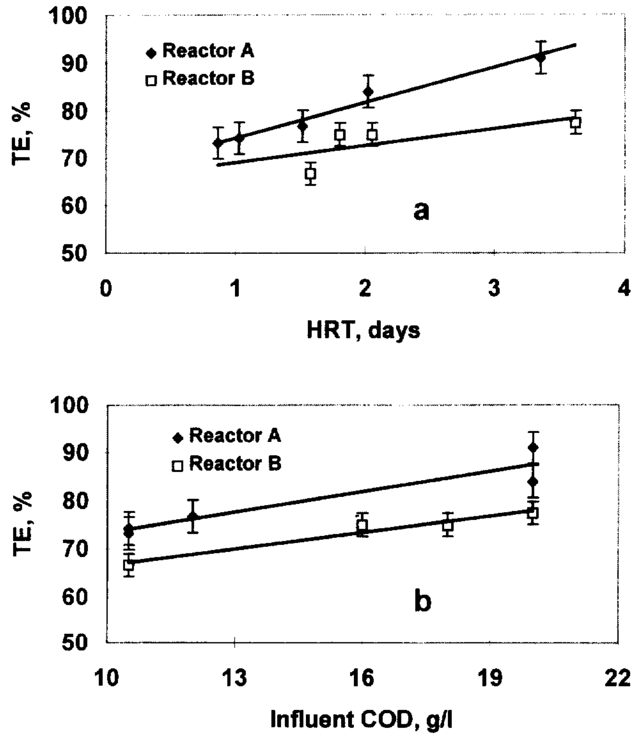

Fig. 2. Influence of HRT (a) and influent waste strength (b) on TE under steady-state conditions ($n = 3$).

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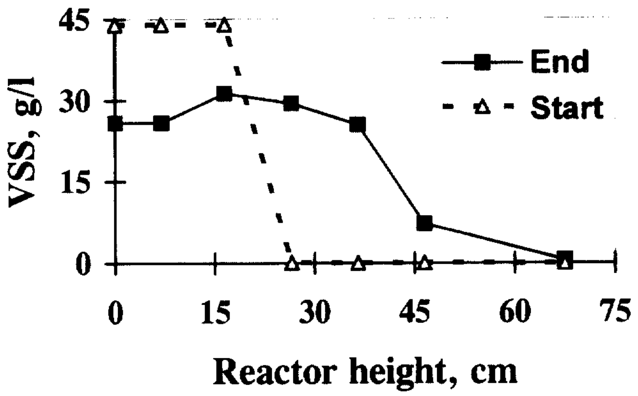

Fig. 3. Sludge distribution in the reactor A at the start and end of the experiments.

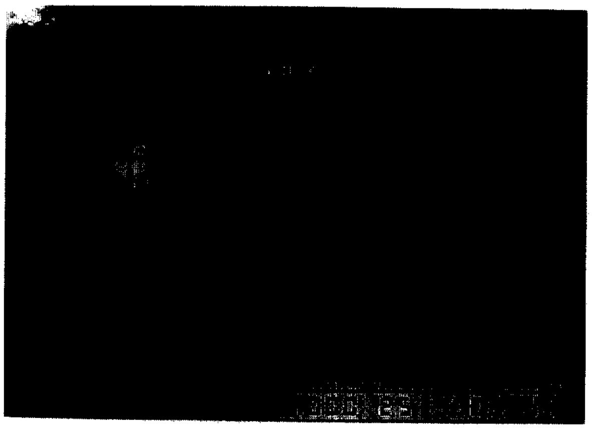

Fig. 4. Electron scanning photography of a segment of decomposed granule (1 cm = 200 μm).

Kovalev for providing hen manure wastewater samples and data about manure production in Russia.

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