Biochemical Engineering Journal 27 (2005) 17–23

Biochemical Engineering Journal

www.elsevier.com/locate/bej

Extraction of volatile fatty acids (VFAs) from water hyacinth using inexpensive contraptions, and the use of the VFAs as feed supplement in conventional biogas digesters with concomitant final disposal of water hyacinth as vermicompost

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Received 4 December 2004; received in revised form 11 April 2005; accepted 3 June 2005

Abstract

A procedure has been developed for extracting volatile fatty acids (VFAs) from water hyacinth (WH) using simple and inexpensive equipment of the type commonly available in the rural households of the third world countries. The VFAs thus extracted were used as feed supplement in cow dung-fed floating-dome biogas digesters. As tens of thousands of such digesters are in operation across the third world, the aim of these studies has been to provide for such digesters feed derived from phytomass, especially for use whenever animal dung is in short supply or is unavailable. The VFA extraction was based on aerobic/facultative degradation of water hyacinth and significant quantities were extracted from each WH charge daily for upto 6 days. When cow-dung slurry was fortified with the VFAs and fed to a conventional biogas digester, it yielded about 22% higher quantity of biogas per unit feed than was obtained from equivalent mass (dry weight basis) of the unfortified cow-dung slurry.

The technique developed by us enables phytomass to be utilized as feed supplement in biogas digesters without causing the problems of solids accumulation, frothing and clogging known to be associated with phytomass feed. After VFAs have been extracted from it, the 'spent' water hyacinth was vermicomposted and used as soil conditioner-cum-fertilizer.

Keywords: Volatile fatty acids; Anaerobic fermentation; Two phase system; Water hyacinth; Biogas; Vermicomposting; *Eudrilus eugeniae*

1. Introduction

Aquatic weeds such as water hyacinth (*Eichhornia crassipes* Mart. Solms) represent easily and widely available organic waste, which can be anaerobically fermented [1–6]. However, the weeds cannot be fed, either directly or after chopping/mincing, to the conventional biogas digesters [7–9]. As the weed phytomass is lighter than water, it rises to the top of the water level in the digester, thereby clogging the digesters [10,11]. Further, water hyacinth (WH) consists of 94–95% water; it barely contains 50–60 g of total solids per kilogram. This necessitates large digester volumes for generating significant quantities of biogas [2,6–9]. Moreover the biodegradability of cellulosic materials under anaerobic conditions is low. This means long retention times and consequently a slow rate of biogas production [2,6–9]. In an attempt to circumvent the multiple problems of feeding, frothing, clogging and low reactor efficiency, when phytomass is fed to the biogas digesters, we have developed a process by which volatile fatty acids (VFAs) are extracted from water hyacinth and the VFAs-laden slurry is then used as feed supplement to the conventional cow-dung fed biogas digesters. The process has been deliberately made inexpensive and simple so that even unlettered

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1369-703X/$ – see front matter
doi:10.1016/j.bej.2005.06.010

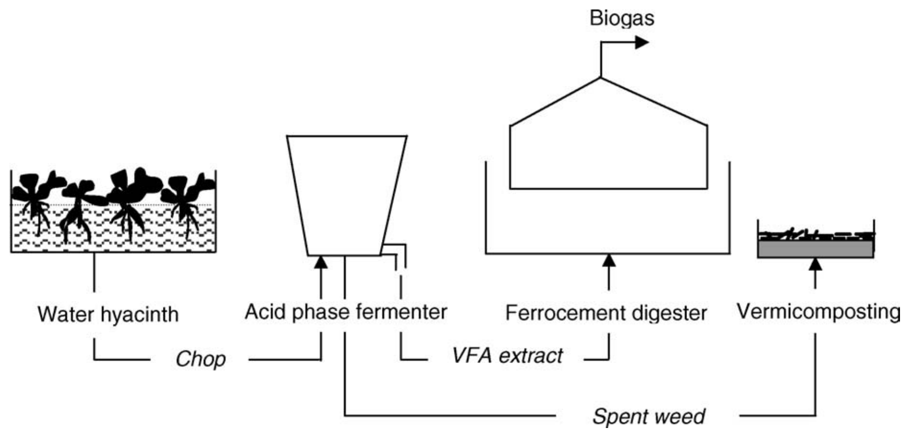

Fig. 1. Schematic representation of the process developed by the authors.

persons from economically challenged background can utilize it.

The VFAs are extracted in 'acid phase' reactors wherein the weed is kept in contact with dilute aqueous cow-dung solution for 24 h and the conditions are so maintained that the system does not become anaerobic. This facilitates the acidogenic and acetogenic bacteria present in cow-dung to act upon the phytomass and convert parts of it to water soluble VFAs [12,13]. Simple, inexpensive and easily available equipment such as plastic buckets, hosepipes, and plastic taps are used for the VFAs extraction so that the process can be easily replicated by even illiterate householders and farmers for augmenting their biogas digesters.

The VFA solution obtained as above is used in place of the dilution water, which is ordinarily used in preparing cow-dung slurry for feeding the conventional biogas digesters [14]. Long-term (over 3 months) trials indicated that the slurry made up of cow-dung and VFAs solution enabled smooth and consistent operation of the digester. The biogas production per unit total solids (TS) loading was ∼22% higher in this digester compared to the ones run on cow-dung slurry alone.

After VFA extraction the 'spent' water hyacinth was vermicomposted in high-rate vermireactors [15]. The vermicompost is a good soil-conditioner and fertilizer [16].

The schematic of the entire process is depicted in Fig. 1.

2. Materials

2.1. Water hyacinth—sampling and processing

Whole plants were collected from fresh water ponds of Pondicherry. The plants were washed liberally with water to remove attached coarse sediments and then cultured in fiberglass tanks over water in which cow-dung was added to supply nutrients. Healthy, adult plants were periodically harvested from the tanks and washed thoroughly with water, then with 5% ethylene diamine tetra acetic acid (EDTA) solution, followed by de-ionized water, to remove particles adsorbed on surfaces [2,17]. After draining off the water, the plants were wiped with filter paper sheets and chopped to pieces of average length ∼5 cm and breadth ∼2 cm.

2.2. Fresh cow-dung slurry (FCDS)

The fresh cow-dung slurry was prepared by mixing 100 g fresh cow-dung with sufficient water to yield 1000 mL slurry.

2.3. Reactors

2.3.1. Acid phase reactors

Plastic containers (Fig. 2a) were used which had plastic taps at the bottom to collect the VFA leachate. The reactor contents were stirred using plastic sticks.

2.3.2. Biogas digester

The biogas digester used to test the efficacy of VFA-fortified cow-dung slurry as feed was a semi-continuous, slug-flow, intermittently stirred low-rate digester (Fig. 2b), essentially floating dome type, fabricated with highly weather resistant ferro-cement [18–20]. It had a working volume of 2 m^3 and its gas holder was centrally supported, so that the holder could be rotated to break the scum underneath and also agitate the digester contents. Pipes were provided for feed inlet and feed outlet. Similar digesters in very large numbers are in operation throughout India, China and other third world countries. [21–25].

3. Experimental

3.1. Acid phase fermentation for the extraction of VFA

The acid phase fermenters were charged with 5 kg water hyacinth, chopped to pieces ∼5 cm long and ∼2 cm broad, and 15 L of fresh cow-dung slurry. The dry weight of the cow-dung was separately determined by oven-drying a known

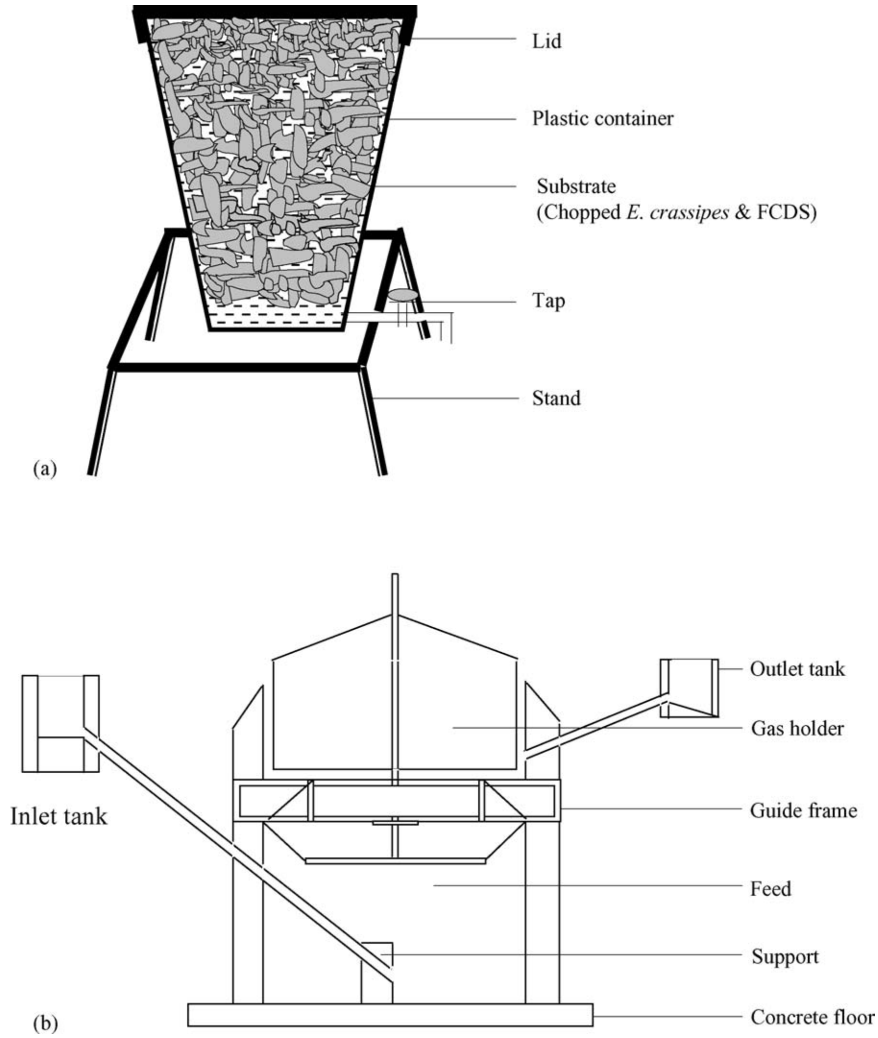

Fig. 2. (a) Acid phase reactors. (b) The conventional semi-continuous slug flow biogas digester. It was used to study the efficacy of the fortification of cow-dung slurry by VFAs obtained from the acid phase reactor (a). The digester is made of ferrocement.

mass to a constant weight at 105 °C; the slurry represented 6.86% of cow-dung (dry weight basis). The reactor contents were stirred with a plastic stick for about 30 s once every 3 h. Each day, i.e., once every 24 h, the liquid content of the reactor was drained out through the tap provided below. Of the total quantity thus removed, 8 L was separated for analyzing its VFA content and for its subsequent use as a biogas digester feed supplement. The rest of the liquid was made upto 15 L with water and put back in the reactor. This process was repeated for 7 days. After the seventh cycle, the portion of the leachate, which was made upto 15 L with water was used to inoculate a new reactor. The new reactor was identical in shape, size and constitution to the first reactor and was also charged with 5 kg water hyacinth chopped to pieces ∼5 cm long and ∼2 cm broad. From the second reactor also, the leachate was drained off once every 24 h and 8 L of it was separated for VFA estimation and subsequent use as biogas digester feed supplement. The remaining leachate was made upto 15 L with water and put back into the reactor.

After a week the process was repeated with a third reactor; 8 L of the leachate coming out on the 7th day were separated for VFA estimation and for use as biogas digester feed supplement while the rest of the leachate was made upto 15 L and used to inoculate the third reactor.

In this manner a series of experiments were continued upto the sixth reactor (Fig. 3a). In another series of experiments done concurrently, 7 L of the leachate were separated each day instead of the 8 L as in the above mentioned experimentals, and the rest made upto 15 L with water and recycled (Fig. 3b).

The experiments were designed in this manner to seek answers to several important questions as explained now. We had started both series of experiments with fresh cow-dung slurry as a source of microorganisms; water hyacinth was the substrate, which the microorganisms were expected to utilize in generating VFAs. FCDS contains several consortia of aerobic, facultative, and anaerobic bacteria. By keeping the reactor aerated and the pH of its contents in the range

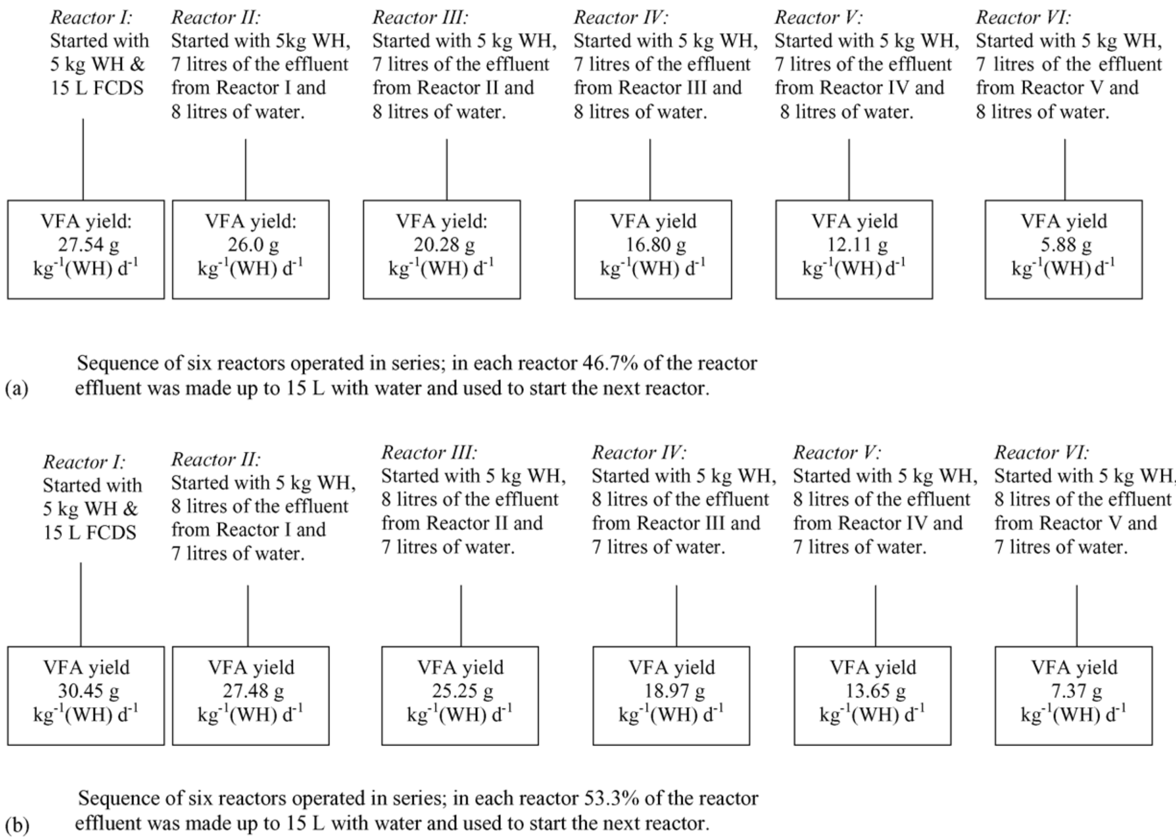

Fig. 3. Sequence of the two series of experiments performed to assess the extraction of volatile fatty acids (VFAs) from water hyacinth.

of 5.5–7.0, we expected the anaerobic microbial population to decline and that of acidogenic (and acetogenic) bacteria to rise. To further dilute other bacteria and to generate conditions better suited for the acidogenic bacteria we removed about half (46.7 or 53.3%) of the reactor liquids each day to be replaced with water. In the series represented by Fig. 3b about 7% more bioleachate was recycled than in the series represented by Fig. 3a. This was done to see whether greater leachate recycle has a favourable impact on the VFA generation. Controls were operated simultaneously in both the series of experiments; these consisted of reactors identical in design and operation to the experimental reactors but operated without any water hyacinth. The control reactors enabled assessment of VFA produced by the FCDS; these concentrations were deducted from the VFA concentration obtained in the experimental reactors to arrive at the contribution of water hyacinth to the VFA generation.

All reactors were operated in duplicate, the results of which agreed within ±5% of each other. The average values are presented in Fig. 3.

4. Results and discussion

The VFA yield per unit mass of water hyacinth, averaged per day from the week-long measurements in each reactor during the two series of experiments, is summarized in Fig. 3. The pattern of VFA yield per day of reactor operation is depicted in Fig. 4. It may be seen from Fig. 4 that in all reactors except the last one in both the series, the VFA yield began to climb up after 2 days of reactor operation and declined sharply from 6th or 7th day. In nearly all cases the 4th day VFA yield was either highest of all days or close to it. Further, after the fifth reactor, the VFA yield per reactor declined sharply, becoming half that of the fifth reactor.

There is also a steady decline in the VFA yield per reactor. The maximum VFA concentration reached in each reactor (Fig. 5) also declines, as one proceeds down each series. This indicates that the concentration of acidogenic bacteria hasn't built up over time down the reactor series as significantly as the authors had expected. The sharp decline in VFA yield after 6th or 7th day in each reactor indicates that operation of the reactors beyond 7th day would not be generating significant concentrations of VFA and that the spent water hyacinth should be replaced in the reactors with fresh one every 6th or 7th day.

Increase in the bioleachate recycle ratio by ∼7% has enhanced the VFA yield by ∼13%; it is therefore recommended that 55–60% of the leachate may be recycled. If still higher proportion is recycled, it would have the disadvantage of leaving lesser portion of the extracted VFAs for use as feed.

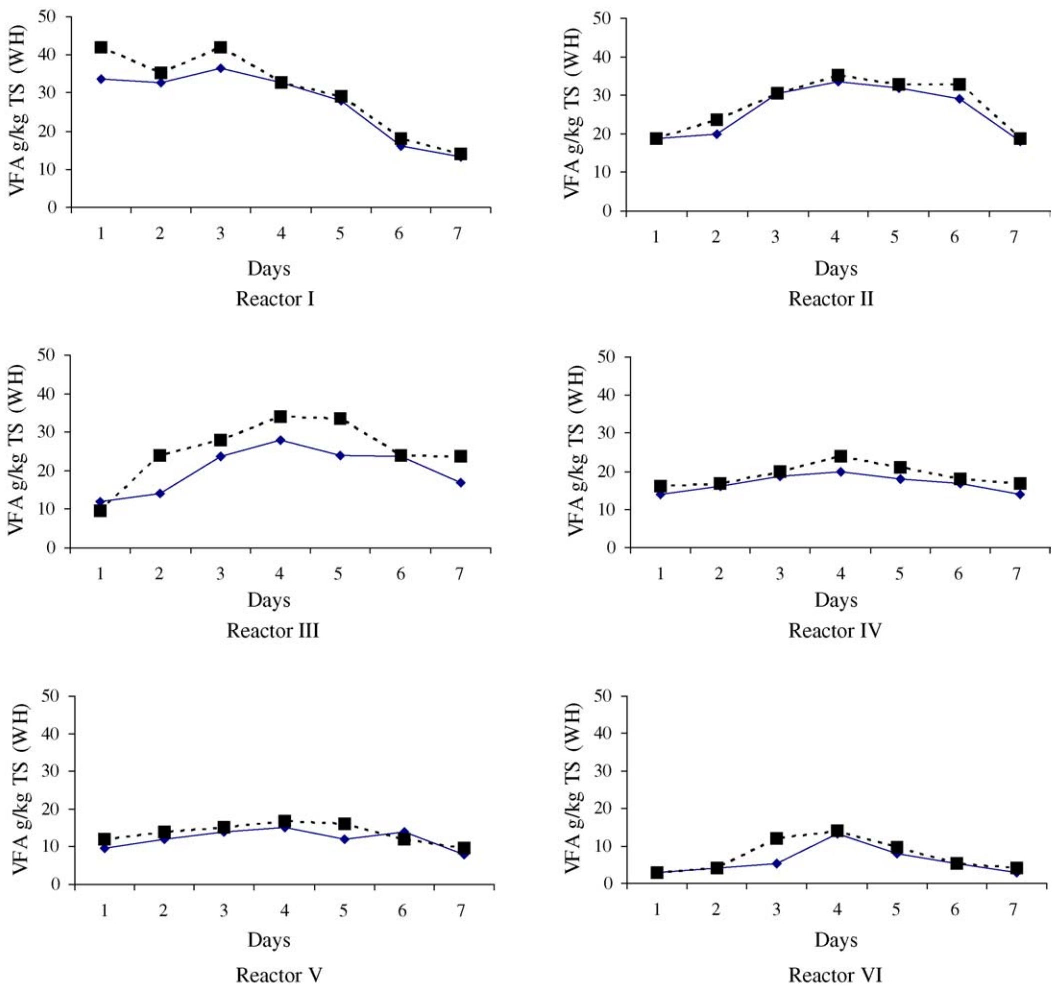

Fig. 4. Daily yield of VFAs in acid phase reactors: Series A (solid line), Series B (dotted line).

4.1. Use of VFA as feed supplement in conventional cow-dung fed biogas digester

The conventional low-rate ferrocement biogas digester (Fig. 2b) was initially operated with a daily feed of cow-dung slurry prepared by mixing 20 kg of fresh cow-dung with 25 L of water. The slurry had TS in the range of 52–53 g/L. After about 6 weeks of operation, the digester turned into the steady state, yielding ∼270 L of biogas per $m^3$of reactor volume per day (Fig. 6a). Thereafter a part of the water being used in preparing the cow-dung slurry was replaced with VFA solution (500 mg/L) of adequate volume to yield the same TS loading per liter of feed as before. The digester attained steady state after ∼70 days, generating ∼330 L of biogas per m^3 of digester volume per day (Fig. 6b). Thus, for the same TS input, the VFA-supplemented feed yielded ∼22% higher quantity of biogas. The higher yield per unit mass of TS in this case is perhaps due to the fact that whereas in the cow-dung slurry only about 65% of the TS is digested [18,20,26], the entire TS content of the VFAs is utilized by the methanogenic bacteria to produce biogas.

The biogas from both types of feeds had identical calorific value; represented by ∼65% methane content.

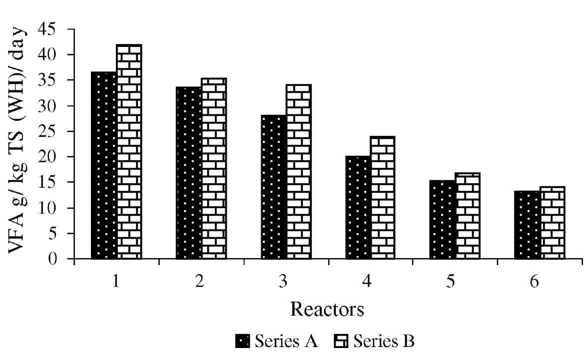

Fig. 5. Peak VFA yield in the acid phase reactors.

4.2. Final disposal of water hyacinth

Water hyacinth taken out from the acid phase reactors after VFA extraction is partially decomposed and soft. It is readily consumed by earthworms *Eudrilus eugeniae*, which convert it into vermicast. We have earlier made detailed studies of

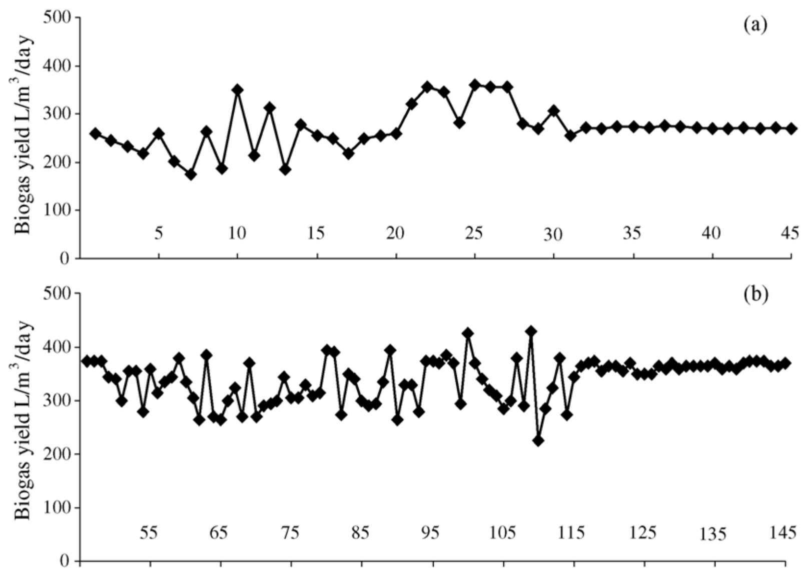

Fig. 6. Biogas production from the conventional slug-flow, low-rate, intermittently mixed biogas digester: (a) when operated with cow-dung slurry without VFA supplement and (b) when operated with VFA-fortified cow-dung slurry at daily TS loading identical to that of the feed representing (a).

the vermiconversion process [15] employing different forms of water hyacinth as feed in vermireactors—fresh whole plants, dried whole plants, fresh chopped plants, precomposted weed, and the 'spent' weed taken from the acid-phase reactors of the type depicted in Fig. 2a. The studies have revealed that the 'spent' weed was vermicomposted nearly as fast as the precomposted weed and if the 'spent' weed was precomposted for a week, it turned out to be the most favoured of the water-hyacinth based feeds; *E. eugeniae* consumed ~200 mg of the weed per animal each day. By employing 'high-rate vermireactors' [27], the spent weed can be quantitatively vermicomposted within 10 days. Field trials have proved that the water hyacinth vermicompost is a good fertilizer [16] and even if such vermicompost falls in water-bodies, it does not cause reinfestation of water hyacinth [28].

Acknowledgements

Authors thank Department of Biotechnology, Government of India, New Delhi for support vide grant No. BT/PR 4741/AGR/21/182/2004. SG thanks Council of Scientific and Industrial Research, New Delhi, for a Research Associateship.

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