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Characterisation of solid and liquid fractions of dairy manure with regard to their component distribution and methane production

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Abstract

Dairy manure with a total solids content of 77.2 g TS/l was separated by means of screening and coagulation–flocculation treatments, using CaO as coagulant and a cationic polyacrylamide as flocculant, obtaining liquid and solid fractions. The solid fraction separated contained 33.4% of the initial total mass of dairy manure plus chemical solutions, containing also 75.2% of the TS, 80.4% of the VS, 58.5% of the total Kjeldahl nitrogen (TKN) and 87.4% of the total phosphorus (P_T) present in the initial dairy manure. 83.7% of the liquid fraction chemical oxygen demand (COD) was anaerobically biodegradable (COD_{BD}). Methane production for the separated liquid fraction was 0.604 l CH_4 NCTP/g VS added, being 0.307 and 0.371 l CH_4 NCTP/g VS added for dairy manure and screened dairy manure, respectively. The characteristics of this liquid fraction would allow its treatment in high loading anaerobic reactors having shorter hydraulic retention times, smaller reactor size and a higher methane volumetric production rate than conventional anaerobic reactors treating either manure or screened manure.

Keywords: Dairy manure; Dewatering; Solids removal; Liquid fraction; Polyacrylamide; Anaerobic biodegradability; Methane production

1. Introduction

The composition of cattle waste depends on the conditions under which animals are kept on the farm (dairy cows, breeding cows and calves). Cattle manure extracted from cowhouses contains residues of food and bedding (straw, sand, sawdust, etc.) in addition to solid and liquid animal wastes. Many of these solids are either not biodegradable or only slowly so. The waste can be collected by means of either mechanical or hydraulic scraping of the floor and dragging of the material into the manure pit.

Separation of liquid and solid fractions of the waste is a desirable upstream operation in the treatment process: dewatering the solid fraction lowers the cost of shipping and increases the energetic yield in combustion processes. When the separated solid fractions have an adequate TS content and VS/TS ratio, then they are suitable for production of compost (Lo et al., 1993) or energy (Møller et al., 2004). If the separated liquid fraction, which features the largest volume, presents low solids and ammonium contents, it can be spread on fields during most of the year without causing environmental problems. After separation, it will be possible to apply the concentrated dry matter and nitrogen-rich fraction during the growing crops season (Henriksen et al., 1998). When manure is collected by washing instead of scraping and dragging the floors, it is more dilute and dewaters more easily through a sieve. There seems to be a rinsing action on the sieve: the more plentiful fluid favours detachment of fine and colloidal solids from longer fibres retained by the screen and these pass through the sieve. Thus, sieved liquid presents a higher volatile solids content in comparison with sieved manure collected from the animal house by scraping and dragging.

Lo et al. (1983) proved that liquid–solid screening separation had a minimal effect on the rate of methane

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production from mesophilic anaerobic digestion of dairy manure for equal volatile solids loading rates at 16 days hydraulic retention time (HRT). For shorter HRT a significant increase was found in the biogas production rate per litre of digester or per gram volatile solids added for the screened manure over unscreened manure. Anaerobic digestion of screened dairy manure, with 3.78% TS, showed that optimum positive net energy yields of 0.213 l CH_4/g VS added can be obtained at 30 °C and 20 days HRT, according to Hawkes et al. (1984). Liao and Lo (1985) studied the technical feasibility of adopting the fixed-film reactor concept for biogas production from screened dairy manure, with 4.4% TS, compared with the conventional reactor at 35 °C. Maximum methane volumetric production rate for the conventional reactor was 0.63 l CH_4/l day at 6 days HRT. For the fixed film reactor the maximum production rate was 3.53 l CH_4/l day when operated at 3 h HRT (loading rate 262 g VS/l day and methane yield 0.0135 l CH_4/g VS added). Lo et al. (1985a) studied the performance of fixed-film reactors treating screened dairy manure at 22 °C on the basis of methane productivity and biodegradation efficiency. For 5.2% VS screened dairy manure feeds, maximum methane volumetric production rate was 1.29 l CH_4/l day at 1 day HRT and maximum methane yields of 0.10 l CH_4/g VS added occurred at 16 days HRT. Lo et al. (1985b) compared anaerobic digestion process results for screened dairy manure (3.4% and 5.2% VS) under mesophilic (35 °C) and thermophilic (55 °C) conditions. For the 3.4% VS at 35 °C, 0.63 l CH_4/l day were obtained as maximum methane volumetric production rate at 6 days HRT, and 0.152 l CH_4/g VS added as maximum methane production at 12 days HRT. The same feed at 55 °C gave 1.03 l CH_4/l day as maximum methane volumetric production rate at 2 days HRT, and 0.149 l CH_4/g VS added as maximum methane production at 15 days HRT. By comparison of two reactors fed with 3.4% VS manure, for HRT's of 6 days and greater, the gas production rates showed that there was no benefit in operating at the thermophilic temperatures. Mesophilic digestion of screened dairy manure using an anaerobic rotating biological contact reactor, plus three sequencing batch reactors for the subsequent aerobic process, achieved a chemical oxygen demand reduction of 98% (Lo and Liao, 1986). In the anaerobic reactor, the maximum methane productivity was 1.89 l CH_4/l day at 1 day HRT, with the highest methane yield of 0.093 l CH_4/g VS added being obtained at 11 days HRT (Lo et al., 1986a). When screened dairy manure was treated using one-phase or two-phase anaerobic digestion systems, maximum production rates of 1.50 and 2.32 l CH_4/l day were achieved, respectively, at 1 day HRT (Lo et al., 1986b). Liao and Lo (1987) reported that methane volumetric production rates were very similar for both the screened manure and supernatants from the sedimentation process. Kalyuzhnyi et al. (1999) reported data from the treatment of liquid cattle manure obtained by dilution and solid–liquid separation from 15–8% TS to 7–4% TS in a UASB reactor. Total COD reduction of 41.5% and a methane volumetric production rate of 0.70 l CH_4/l day at a maximum organic loading rate (OLR) of 6.63 g COD/l day at 1 day HRT were obtained. Excepting the data reported by Lo and Liao (1986), COD removal percentages were always below 50%, in accordance with the biodegradability of both unscreened and screened manure.

Taking into account the different kinetics of hydrolytic–acidogenic and methanogenic stages, Nozhevnikova et al. (1999) proposed a two-step anaerobic manure treatment in which both sanitation of manure and energy saving were present: (i) acidogenic fermentation at high temperature, (ii) solid and liquid fractions separation, (iii) treatment of liquid fractions under low temperature conditions.

Previous experiments to separate liquid and solid fractions have been performed by Burcham et al. (1997), Gilbertson and Schulte (1987) and Mohri et al. (2000) with mechanical separators and settling tanks. If a better liquid–solid separation is desired, coagulation–flocculation is a suitable way to attain this goal. In addition to the mechanical separation of liquid and solid fractions in animal wastes, salts of Fe^{3+} and Al^{3+} and CaO have been used together with polymers as methods to improve the efficiency of coagulating and settling fine and colloidal solids. Barrow et al. (1997), Bolto et al. (1999), Vanotti and Hunt (1999), Shang-Kyu and Gregory (2001) and Sievers et al. (1994) have reported coagulation–flocculation experiences with animal wastes. Zhang and Lei (1998) have reported the use of salts together with polymers to improve the removal of phosphorous considerably. McKenney (1998) tested aluminium sulphate as coagulant to improve the collection of solids, followed by sedimentation and dewatering of the sludge in a belt filter press. The main difficulty that appeared was that the high solids content in the sludge (10–13%) hindered the operation of the pumps. After various changes in the process, pumps and filters, solids removal efficiencies reached values between 71% and 78%. Removal of nutrients stayed around 70% for phosphorous and 40% for nitrogen.

Cantabria, a region in Northern Spain, has about 350,000 dairy cows which generate around 4,500,000 tonne/year of semi-liquid manure (7–14% TS). Most of the intensive farming is operated on the coastal flatlands, which are tourism areas. Manure storage capacity is limited and there is not enough land available for waste disposal by direct application during those periods when the soil benefits from nutrient additions, which leads to environmental damage. Williamson et al. (1998) came to the conclusion that intensive-production farms should use specialised technologies if they wish to keep operating in sensitive zones, where the traditional method of using wastes as land fertilizer is either not applicable or exceeds the land acceptance capacity.

In humid areas, particularly where the ground shows pronounced slopes, as happens in many zones of Cantabria, the liquid fraction of manure is responsible for part of the pollution found in superficial and underground waters. The intention to develop solutions for this problem was the origin of