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High rate manure supernatant digestion

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ABSTRACT

The study shows that high rate anaerobic digestion may be an efficient way to obtain sustainable energy recovery from slurries such as pig manure. High process capacity and robustness to 5% daily load increases are observed in the 370 mL sludge bed AD reactors investigated. The supernatant from partly settled, stored pig manure was fed at rates giving hydraulic retention times, HRT, gradually decreased from 42 to 1.7 h imposing a maximum organic load of 400 g COD L^{-1} reactor d^{-1}. The reactors reached a biogas production rate of 97 g COD L^{-1} reactor d^{-1} at the highest load at which process stress signs were apparent. The yield was ~0.47 g COD methane g^{-1} COD_T feed at HRT above 17 h, gradually decreasing to 0.24 at the lowest HRT (0.166 NL CH_4 g^{-1} COD_T feed decreasing to 0.086). Reactor pH was innately stable at 8.0 ± 0.1 at all HRTs with alkalinity between 9 and 11 g L^{-1}. The first stress symptom occurred as reduced methane yield when HRT dropped below 17 h. When HRT dropped below 4 h the propionate removal stopped. The yield from acetate removal was constant at 0.17 g COD acetate removed per g COD_T substrate. This robust methanogenesis implies that pig manure supernatant, and probably other similar slurries, can be digested for methane production in compact and effective sludge bed reactors. Denaturing gradient gel electrophoresis (DGGE) analysis indicated a relatively fast adaptation of the microbial communities to manure and implies that non-adapted granular sludge can be used to start such sludge bed bioreactors.

1. Introduction

Governments promote anaerobic digestion (AD) of manure because it can reduce greenhouse gas (GHG) emissions and odors, produce renewable energy as methane and improve fertilizer properties (Masse et al., 2011). The largest potential source of methane by anaerobic digestion (AD) of wet organic waste is manure, e.g. ~40% in Norway, but an insignificant fraction of this is realized (Berglann and Krokann, 2011). The main reason for this is the low energy density of manure, implying low production rates in continuous flow stirred tank reactors (CSTR) currently used for manure AD. Such solutions are not sustainable because the costs of construction and operation of such plants are larger than the value of the methane produced (Berglann and Krokann, 2011). Large scale

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farms may have their own CSTR AD solutions that are economically sustainable (Raven and Gregersen, 2007) but agriculture is dominated by smaller farms where such systems may not be rentable. Manure transport to central AD treatment plants is used to some extent, especially in Germany, but the sustainability of such solutions is questioned due to transport cost of manure with low biogas potential.

More efficient process solutions for AD treatment of manure are therefore required. High rate AD reactors may treat waste in smaller and presumably much cheaper digesters. A high rate AD manure treatment technology that is well integrated with existing farm infrastructure for slurry based manure handling systems, common for cattle and pig farms (Burton and Turner, 2003), is therefore investigated here. Manure from farms using slurry based handling systems has 61% of the total theoretical Norwegian manure energy potential of 2480 GWh/a (Raadal et al., 2008). The situation vary some around the world but it is assumed that the case investigated here is relevant for a large fraction of modern global agriculture, as well as aquaculture and other activities producing organic waste slurries.

Manure storage tanks with 8 months minimum HRT capacity, already installed in cold climate countries (e.g. Norway, to comply with government regulations to avoid use as fertilizer outside the short growth season), may serve as a first step in an AD treatment line and/or be used for effluent storage. It has been observed that manure particles disintegrate and hydrolyze during such storage, thereby improving its quality as AD feed (King et al., 2011; Bergland et al., 2014). In such tanks manure separates spontaneously into a floating layer (straw, wood chips, etc.), a bottom sediment layer and a middle layer with much less suspended solids than the floating and bottom layers (Fig. 1). Potentially suitable high rate AD feed can be taken out from the middle layer at no extra cost. A main issue of the present study is to determine if this middle layer, termed manure supernatant, can be used as feed for high rate AD. The assumption is that, if a sludge blanket high rate AD works well on such feed, this process can become economically feasible.

The original and most extensively used high rate reactor is the UASB (upflow anaerobic sludge blanket), developed by Lettinga et al. (1980). Such sludge blanket reactors are used to

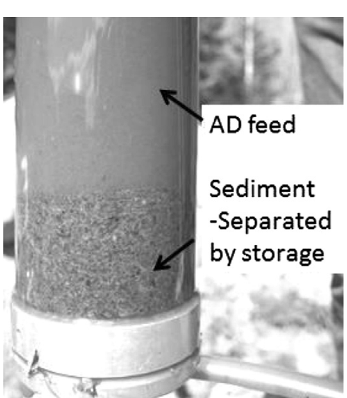

Fig. 1 – Pig manure sample collected near the bottom of a pig manure storage tank.

treat the liquid fraction of organic waste containing small amounts of suspended solids (Tchobanoglous et al., 2003). The particle content of settled manure (Fig. 1) is higher (>6 g TSS L^{-1}) than recommended for UASB treatment (Tchobanoglous et al., 2003). Alternative high rate AD designs, such as fixed biofilm reactors, have been tested on such wastes but solids build up blocking the void spaces in the filter medium making such alternatives less promising (Bolte et al., 1986). Hybrid UASB (Lo et al., 1994) and a suspended particle-attached growth (SPAG) reactor (Cobb and Hill, 1989), are also available. The UASB is, however, the standard of high rate AD, so a small UASB like sludge bed reactor design was chosen for the present study to test the possibilities of high rate AD slurry treatment.

The objective of this study was to examine the efficiency, flexibility and stability of manure supernatant AD treatment in sludge bed reactors. The process capacity and robustness was evaluated by measuring manure degradation and product formation for a wide range of loading rates, including loads that are much higher than what is expected to be required or optimal. A PCR/DGGE strategy was employed to characterize the microbial communities, and to evaluate the time needed for adaption of the granular inoculum to the conditions in the manure-fed AD reactors. The study is relevant for the development of efficient wet organic waste AD with low energy density and high particulates contents in general (e.g. manure, wastewater treatment plant sludge, aquaculture waste sludge) and it may be decisive for the development of sustainable solutions to recover energy for slurry type manures.

2. Materials and methods

2.1. *Manure properties and handling*

The process feed was pig manure slurry supernatant regularly collected from a production farm in Porsgrunn, Norway. The manure comes from barns that contains 105 sows, 315 “farrow to finish” and 545 weaners that are fed protein concentrate (14.6% crude protein) added some grass/straw. Wood shavings and straw are used as bedding material. The manure is transported into a storage pit where it is diluted about 30% by wash water from regular barn washing routines. This mixture is what we define as manure slurry, according to Burton and Turner (2003). The HRT of the storage pit varies from 70 to 90 days, which has no significant effects on manure composition (Bergland et al., 2014). The manure separated by gravity in the storage pit into three distinct layers. The top layer is wood shavings and straw. Heavy particles settled to form a bottom layer (Fig. 1). The middle layer, termed the manure slurry supernatant (Table 1), was siphoned and used as feed without any filtering. Fresh manure supernatant was thus collected frequently and stored at 4 °C until use.

2.2. *Reactor design and start up*

The reactor is a simplified UASB (Fig. 2a) made of a 370 mL glass vessel with 345 mL liquid volume, height 130 mm and diameter 60 mm. The substrate inlet is a central tube ending