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Start-up of dry anaerobic digestion system for processing solid poultry litter using adapted liquid inoculum

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ABSTRACT

The objective is to obtain the basic design criteria for starting up dry anaerobic-digestion (DAD) systems treating solid-poultry-litter (PL) with hay-bedding ($TS_{mixture}$: 68.6%) using adapted liquid inoculum. Effect of organic loading rates (OLR) and mode of operation (particularly psychrophilic liquid inoculum recirculation-percolation mode) were evaluated in two phases; such that OLR of 5.4 and 21.6 $gVS/kg_{inoculum}VS/d$ were maintained respectively for Phase-1 and-2; and top-down and down-up mode of liquid-inoculum recirculation into DAD-system were experimented. Digesters were operated at psychrophilic-temperature (@20 °C) with cycle length of 26 and 38 d for Phase-1 and -2, respectively. Results show that specific methane yield of 0.147–0.162 L/gVS_{fed} was obtained for Phase-1 with a methane content of 35–39%; whereas Phase-2 had 61–70% lower yields compared to Phase-1. Though PL-digestion was possible at OLR <5.4 g $VS/kg_{inoculum}VS/d$, high nitrogen-content in PL inhibited the digestion process especially at higher OLR. However, adapted inoculum to TKN of >20 g/L could minimize the inhibition. Top-down-recirculation is recommended for simpler operation.

1. Introduction

Improperly managed poultry wastes can cause drastic damage to the environment, which can harmfully influence human and animal health. On the other hand, poultry litter (PL) is a potential organic substrate for biogas production through anaerobic digestion (AD), which has not been fully utilized so far, due to the key issues linked with inhibition caused by high concentration of ammonia in chicken litter (Abouelenien et al., 2014). In 2006, Canadian livestock produced over 180 million tons of manure over the year; of this total about 5 million tons produced by poultry (Statistics Canada, 2008). PL contains 20% or more dry matter, and the anaerobic decomposition of uric acid and undigested proteins in PL results in the production of high amounts of unionized ammonia and ammonium ions (Bujoczek et al., 2000; Abouelenien et al., 2009). In addition, PL is a poor substrate, due to presence of high total Kjeldahl nitrogen (TKN), which led to imbalanced carbon to nitrogen ratio. The optimal carbon to nitrogen (C/N) ratio of 15–30 is preferred for AD and hence external supplementation of carbon has to be regularly performed to dilute TKN concentration, in order to achieve a stable and efficient process (Babaee et al., 2013). It is to be noted that dilution can be done by adding water; however, it is not practically feasible due to the huge amount of dilution required.

Anaerobic digesters can be operated under liquid (wet), semi-solid, or solid-state (dry) conditions, when the total solids (TS) of substrate are <10%, 10–15%, or >15%, respectively (Li et al., 2011). Largely, liquid AD is frequently applied in full scale operations, owing to reasons such as easy operation

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and maintenance, and increased methane yield (Fdez-Guelfo et al., 2010). Nevertheless, liquid AD is not suitable for high solid content wastes, for instance solids fraction of animal manure with bedding materials, due to the higher dilution requirements and hence larger volume of digesters required to treat the feed material. On the other hand, solid state digestion enables a higher volumetric organic loading rate, small reactor volume, lower energy requirements for heating, positive energy balance (Jha et al., 2011). However, solid state digesters need longer retention time and huge amount of inoculum over wet digestion systems and often resulted in poor start-up performance due to incomplete mixing and accumulation of volatile fatty acids (VFAs) (Jha et al., 2011; Li et al., 2011). Some researchers have reported notable effects of temperature on the microbial community, process kinetics and stability, and methane yield. Lower temperatures during the AD process are known to decline the microbial growth, specific substrate utilization rates, and methane production (Babaee et al., 2013). On contrary, digesters operating at high temperatures resulted in lesser biogas yield due to the production of volatile gases such as ammonia which suppresses methanogenic activities (Khalid et al., 2011).

Co-digestion of manure with energy crops/crop residues (like straw or hay) or other carbonaceous wastes can increase the biogas yield. In addition, it helps to maintain an optimal pH for methane producing bacteria, decreases free ammonia/ammonium inhibition, which may occur in AD of PL alone, and provides a better C/N ratio in the feedstock (Xie et al., 2011). Few researchers have explored the co-digestion of poultry manure with other organic wastes, as demonstrated in Table 1. However, (i) the study demonstrating the feasibility of treating chicken litter (with hay bedding) at higher TS content of above 15% is limited; (ii) low-temperature treatment of these co-substrates has not been reported (Table 1); (iii) in addition, starting up of solid dry anaerobic digester (DAD) using liquid inoculum from adapted inoculum storage has not been extensively studied, as huge amount of dry inoculum is hard to find for starting the digesters. This concept is expected to enrich the methane production and hence the performance in an economical way. Premixing of substrate with inoculum would provide a better waste–microbe interaction at the first hand. Liquid inoculum percolation-recirculation is expected to eliminate the need for mixing equipment within the digesters and thus, would enhance the waste–microbes interactions in the DAD reactor during the digestion process. Presence of hay or straw as a structural material in the waste matrix should improve the percolation rate.

Thus the objective of the present study was to determine the operational feasibility of solid dry anaerobic digester (DAD) treating PL with hay bedding using adapted liquid inoculum as a seeding source. Liquid inoculum recirculation-percolation method of operation was carried out at psychrophilic temperature (20 ± 0.5 °C). A separate liquid inoculum reservoir (reactor) was used to provide the aforementioned adapted inoculum (biomass), so that it can be used to speed up the digestion of DAD process and improve the energy production and biomass quantity compared to the static DAD operation without inoculum. The liquid inoculum reservoir also produces energy from VFAs that are washed out of the DAD reactors by the inoculum recirculation. The transfer of VFAs from the DAD reactor to the inoculum reservoir is expected to reduce the risk of VFAs accumulation and inhibition in the DAD reactors. Special attention was given to the mode of operation and its procedures to operate the reactors with minimal inhibition.

2. Methods and materials

2.1. *Feedstock and inoculum*

Fresh chicken litter was collected from a local commercial poultry operation located near Sherbrooke (Quebec), Canada. Collected PL contained hay bedding. For characterization purpose, the manure samples (i.e. mixture of PL + hay) was then grinded to prepare homogenize feed samples; however, for experimentation purpose, raw manure with hay material (without grinding) was used as a feedstock and stored in a cold room at 4 °C to prevent biological activity until needed for feeding.

The liquid inoculum was obtained from a laboratory-scale wet-digestion bioreactor located at the Dairy and Swine Research Development Centre (DSRDC), which was processing pig manure + chicken pellets at high ammonia concentrations (7–8 g TAN/L). The inoculum was diluted with water to bring down the TS content from 9% to 5%, so that it could percolate more easily into the void spaces of the porous solid substrate matrix of the DAD reactor. Liquid inoculum at 5% TS was stored in a gas tight reservoir (reactor), prior its intermittent recirculation into the solids DAD rector whenever needed.

2.2. *Experimental set-up and procedures*

The operational feasibility of solid DAD treating PL + hay using liquid inoculum recirculation-percolation method of operation were experimented in two phases. Fig. 1 presents the schematic representation of the DAD + liquid recirculation-percolation system.

Phase 1 of the study consisted of two stage AD system: DAD reactor (BR1) + inoculum reservoir (BR2) [20-L active inoculum volume]. Two sets of digesters (in replicates) namely BR1a + BR2a and BR1b + BR2b were operated in parallel and were installed at a controlled-temperature room, which was maintained at 20 ± 0.5 °C. The solid substrate was fed in a batch feeding mode and a cycle length of 26 days was maintained. No mechanical mixing was applied. About 4-L of inoculum from the inoculum reservoir was pumped and sprinkled at the top of the DAD system; such that it

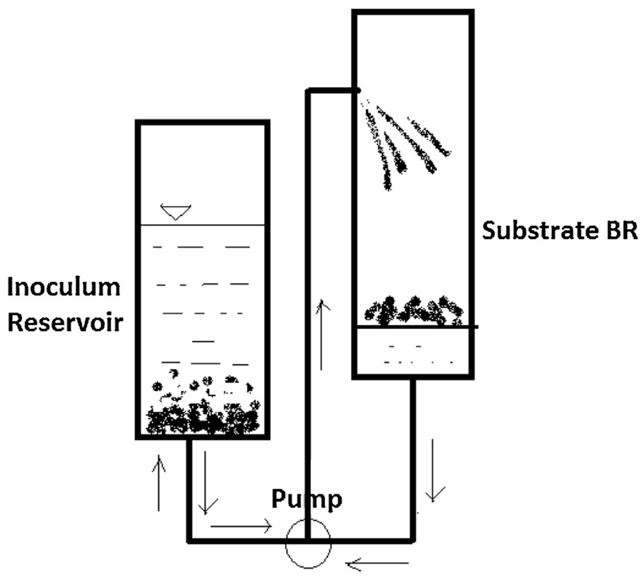

Fig. 1 – Schematic representation of DAD + liquid inoculum recirculation system.