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Towards optimization of the total solid content in high-solid (dry) municipal solid waste digestion

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HIGHLIGHTS

- Pilot scale results for high solid anaerobic digestion are presented.
- The influence of the total solid content was investigated in continuous mode.
- At 22% inlet total solid, solid segregation took place.
- At higher solid content, good mixing was achieved but poorer methane production.
- An optimum for total solid in the reactor can be found between 20% and 22%.

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ABSTRACT

The influence of the total solid content on the performance of high-solids waste digestion has been investigated on a 50 L reactor. The feedstock was residual municipal solid waste. The reactor has been operated in semi-continuous mode during 3 periods at various total solid content in the inlet (22%, 26% and 30%). Steady-state results showed that the biogas and methane production was slightly lower at 30% TS in the inlet, with an increase of the volatile fatty acid concentration. Nevertheless, solid segregation occurred more likely at low inlet TS (22%). Referring to the volumetric biological activity, it appeared that the optimal TS in the reactor is closed to 20–22%. In our case, this would correspond to an inlet TS concentration of 26–28%. At such TS content, the segregation effect would be limited and the biological activity is kept at a high level.

1. Introduction

Due to the European Landfill Directive (2006/12/CE), the total quantities of disposed biodegradable waste has to be strongly reduced by 2016. Biodegradable waste means any waste able to be decomposed aerobically or anaerobically. The separate collection of biodegradable waste have permitted to develop biological treatment options, like anaerobic digestion and/or composting. However, the separate collection is not so common in EU countries, where sorting only concerns glass and recyclable plastics, paper and cardboard. In this case, the remaining waste is called residual municipal solid waste (MSW). As an alternative to landfilling, residual MSW can undergo mechanical biological treatments (MBT) and anaerobic digestion is one of the techniques that enables to comply with the directive, since a large amount of biodegradable organic matter is converted into biogas during the process.

Anaerobic digestion (AD) technologies are thus particularly attractive for the treatment of biowaste and of residual MSW. Common technologies are referred to as "wet" and "dry" processes, depending on the total solid (TS) content (10–15% for wet, 24–40% for dry, as defined by Luning et al. [1]). There have been few investigations about the operation of dry digesters (also called high-solid digesters) up to now, even if they represent today more

Abbreviations: AD, anaerobic digestion; BMP, biochemical methane potential ($L_{CH_4,STP}$ kg_{VS}); CELL, cellulose ($\%_{VS}$); COD, chemical oxygen demand on solid material (mg_{O_2} g_{FW}^{-1}); FW, fresh waste; HEM, hemicellulose ($\%_{VS}$); HRT, hydraulic retention time; MSW, municipal solid waste; MS, mechanically sorted; N-NH_3, ammonia nitrogen (g_N kg_{FW}); OFMSW, organic fraction of municipal solid waste; OLR, organic loading rate $\left(kg_{VS}\ m_R^3\ d^{-1}\right)$; RES, residual ($\%_{VS}$); SOL, soluble fraction ($\%_{VS}$); SS, source sorted; STP, standard temperature and pressure; TKN, total Kjeldahl nitrogen (g_N kg_{FW}); TS, total solid ($\%_{wS}$); TS_{in}, incoming total solid ($\%_{FW}$); TS_{out}, outcoming total solid ($\%_{FW}$); $TS_{reactor}$, total solid inside the reactor ($\%_{FW}$); TVFA, total volatile fatty acids (g_{COD} L^{-1}); VFA, volatile fatty acids (g_{COD} L^{-1}); VS, volatile solid ($\%_{FW}$); VS_{out}, outcoming volatile solid ($\%_{FW}$); α, segregation index (α_{GB} for glass beads, α_{PB} for polyamide beads).

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than 60% of the constructed plants on the market [2]. At such high TS contents, many questions arise concerning the physico-chemical characteristics, the biological kinetics, and the mechanical features of the digesting medium. More specifically, the common question raised by operators is about the monitoring of the moisture content since TS content in the reactor can be adjusted by water recycling to the incoming waste stream.

Former studies have demonstrated the high potential of dry processes. By comparing wet (incoming TS of 7% TS_{in}) and dry reactors (30% TS_{in}) treating the same feedstock, Rivard et al. [3] observed that the dry process had a higher biogas volumetric efficiency. In their study however, since the retention time was the same in both configurations, the organic loading rate was thus much higher in the dry process, which explains in part the results. Poggi-Varaldo and Oleszkiewicz [4] present systematic investigation on incoming TS (25%–30%–35%–40% TS_{in}) and temperature (39 and 53 °C). The volumetric biogas production reached its optimal value at 30–35% TS_{in}, and it dramatically dropped at 40% TS_{in} whereas volatile fatty acids (VFA) accumulation was observed even at 35% TS_{in}.

Pavan et al. [5] compared different mixtures of source sorted (SS) and mechanically sorted (MS) MSW (ratio of 0–100%) in thermophilic mode. Source sorted waste are more degradable than mechanically sorted ones. At constant HRT (12 days) the limit for reactor stability was around 6 $kg_{VS}/m^3/d$ for SS waste, and it can be doubled for MS waste (since the biodegradable amount of organic matter is 2-fold lower). Since the incoming TS content varied between 10% (SS-MSW) and 25% (MS-MSW), TS content of reactors varied accordingly between 5% and 14%. Similarly, Fernandez et al. [6] investigated the influence of initial substrate concentration on batch anaerobic digestion of organic fraction of MSW (20% TS_{in} vs. 30% TS_{in}). The 20% TS_{in} reactor performed better, even if the results obtained in discontinuous (transient) mode are difficult to extrapolate to continuous reactor. Similar behaviors were shown by the same team [7] in batch mode using food waste. On the other hand, Luning et al. [1] compared wet (Vagron) and dry (Valorga) technologies at the industrial scale. Comparable performances were obtained in term of volumetric efficiency. They identified that the wet process consumed more water and had a lower solid stream to dispose. In counterparts, no solid segregation occurred in the dry process.

Researches were also devoted to the biological activity in dry systems. Lay et al. [8] observed a decrease of the specific methanogenic activity with increasing TS content at lab scale, but the conditions were rather different than that observed in full-scale digesters. Pommier et al. [9] investigated the influence of water content on methanogenic activity; the limit value above which methane production rate starts to decrease was ranged between 1.8 g_{H_2O}/g_{TS} (*i.e.* 35.7% TS) and 2.1 g_{H_2O}/g_{TS} (*i.e.* 32.2% TS) depending on the substrate. In addition, Le Hyaric et al. [10,11] developed specific methanogenic activity tests for high solid systems. They showed that the specific activity decreased when the TS content increases from 18% to 35%. However, this decrease was affected by the type of substrate: it was more pronounced with cellulose than with acetate or propionate.

From the reported literature, it is thus difficult to make a clear opinion on the influence of TS content on AD of solid waste. According to some authors, operating under high TS content permits high volumetric loading rates, whereas, for other authors, there is a TS content limit which can affect the reactor performance, especially concerning the specific activity. Much probably, high TS contents present some advantages, but also some limits. Trying to find optimal operating conditions for TS content in high solid anaerobic digestion is thus a crucial point. Very few data for semi-continuous or continuous operation of high-solids anaerobic digestion are available in the literature in the operating range between 20% and 30% TS. Many questions remain unanswered concerning the operational limits of dry processes. It is rather clear that the specific activity decreases above a certain limit ranged between 25% and 35% TS depending on the authors. However, operating at high TS content enables higher volumetric loading rate (and thus higher volumetric activity). In addition, mechanical problem can also occur when operating at low TS content (mostly sedimentation) or at high TS content (high viscosity/mechanical problems). It is thus the objective of the present paper to investigate on the operating limit of MSW dry digesters. The work has been carried out in semi-continuous mode. The mixing efficiency and the segregation (sedimentation) potential of the solids of the reactor were also investigated through tracer assays on the solid phase.

2. Materials and methods

2.1. Reactor design and operation

The laboratory-scale dry anaerobic digester was based on VALORGA® technology, one of the world-wide leaders in the field of anaerobic waste treatment (Fig. 1). It consisted of a 58 L cylindrical Plexiglas vessel (working volume = 44 L), with a height of 490 mm and a diameter of 390 mm. The main characteristic is the complete absence of any mechanical equipment inside the reactor. The digested media was mixed by a sequential injection of recycling biogas through 14 injectors located at the bottom of the reactor. The biogas was stored in the 40 L gasholder. During the mixing cycles, the valve V2 was closed and V1 was open. The compressor C was switched on until the pressure in the pressurized gas tank P reached the desired value. Then, the biogas was injected at the bottom of the reactor through pinch valves opening in sequence. Once the biogas has been delivered in every 14 injectors, the mixing cycle was stopped, the valve V3 was opened in order to release the remaining pressurized gas in the gas holder. Then, valve V3 and V1 were closed, and V2 was open in gas-counting mode. The whole system was managed by an automate. Another important feature is the vertical median inner-wall on approximately 2/3 of its diameter. Inlet, at the top, and outlet, at the bottom, are located on both side of the inner wall, which forces the organic matter to follow a circular path around it. The reactor was placed on a weighing scale and was maintained at 35 °C thanks to a circulating water bath in a double jacket.

The laboratory-scale digester was inoculated with 43 kg (total reactor active volume) of digestate (TS 17.8%, VS 8.5% on FW basis) from an industrial mesophilic dry digester located in France and

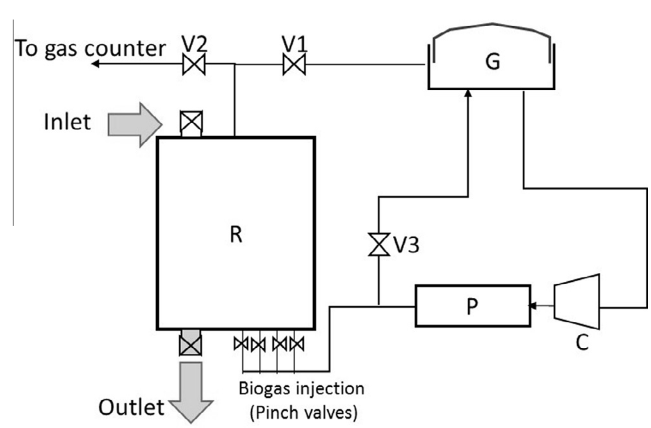

Fig. 1. Schematic view of the experimental apparatus. R: reactor; G: gasholder; C: compressor; P: pressurized gas tank; V_i: electrovalves.