Start-up of a multi-stage system for biogas production and solid waste treatment in low-tech countries

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Abstract Vegetable fruit garden wastes were treated anaerobically using a multistage Dranco system. The digesters were composed of three 50 L vessels kept in mesophilic conditions. They were operating at 14.5–17% TS. By controlling the pH in the system, the start-up for biogas production was shortened to 60 days. The pH correction was a buffering which enhanced methanogenic activity in the digesters. With a loading rate of 4.1 kg VS/m³reactor.day, the production of biogas was 5 m³/m³reactor.day, and 60–70% methane content. This allowed making a multisystem by starting every 3 weeks with new vessels in order to maintain biogas production, to be used in industries or in local communities in low-tech countries. The designed model was started in Kinshasa (Congo) where a project is expected to treat one ton of solid waste on a daily basis, for a production of 100 m³ biogas. This cost effectiveness of the system is demonstrated and presents the opportunity for biowaste treatment coupled with environmental protection and substantial energy recovery.

Keywords Biogas production; multistage system; organic loading rate; solid waste; start-up; total solid

Introduction
Dry anaerobic composting of solid waste needs further development for low-tech countries. Start-up of anaerobic digestion of municipal solid waste (MSW) always poses problems of minimizing the time for biogas and methane production. In normal landfills, this occurs normally after 20–40 years while in a controlled vessel, it appears to be functional after 3–4 months (Van Meenen et al., 1988), provided the temperature is high enough (thermophilic conditions). In mesophilic conditions this takes longer. When starting anaerobic digestion, one should evaluate the process from the knowledge of biogas production and decide whether or not an increased loading of the reactor is possible. The consequences are that the “cautious operator” keeps the loading low to be sure to avoid overloading. But the process will then run at a sub-optimal level and the microbial population will be present in a slow and undynamic state. The second type of strategy is performed by the “brave operator”, who keeps increasing the reactor loading resulting in an increased production of biogas until the point where the process is overloaded and process failure occurs. In both, there is no qualified information about the state of the process and a possibility of remediate imbalance at an early stage.

At mesophilic conditions, solid-states anaerobic digestion is more difficult, because of their instability. The instability in high solid reactors has been overcome using several processes such as a multiple leachate recycling configuration developed by Chynoweth and Pullammanappalli (1996). Other authors have claimed success with the anaerobic digestion of waste at ambient temperature, which is known to be cost effective.

The pH is an important factor to control during the anaerobic digestion. When lower than 7, acidification occurs with subsequent methanogenic inhibition and reduction in biogas production, due to accumulation of volatile fatty acids (Kayhanian, 1999; Lissens et al., 1999).
When higher than pH 8, inhibition also occurs, due to ammonia production in the digested material. The pH may be controlled when starting the process. During start-up, pH stability is of paramount importance, probably for reasons of cell maintenance requirements (Megaert and Verstraete, 1987). The optimal pH for start-up of methane reactors is in the region 6.0–7.0, and not above. In this work, a process has been designed which implies the use of vegetable fruit garden (VFG) waste for biogas production at a low cost, applicable in low-tech countries.

The objective of this work was to perform under mesophilic conditions (about 30°C), an anaerobic digestion process of solid waste, in multiple-stage vessels and one-way feeding. The preference has been accorded to mesophilic conditions due to the fact that the thermophilic bacteria are more sensitive to temperature fluctuation outside their optimum range and ammonia toxicity is more likely to occur in a thermophilic digester than in a mesophilic digester.

The process provides a constant gas production readily available for individual or industrial use. The basic principle was to simulate the condition prevailing in low-tech countries, so that no sophisticated methods should be used to study the performance of the digesters, except the methane analyses.

Material and methods
Three 50 L containers containing VFG wastes from WATCO Company in Gent (Belgium), were used to start the experiment on multistage anaerobic digestion, with the following treatments: 30 kg of wet waste, most of which was fibers, straw-like wastes.

The vessels were placed horizontally on the floor, and mixing was done by rolling the vessels manually every day. Gas outlets from all vessels were connected to a common water column. Every three weeks after gas production had started, three new digesters were started.

A heater was placed, so that the temperature in the room could reach 34°C and varied between 24 and 34°C.

As an inoculum, 4 L of anaerobic granular sludge were used in each vessel.

Appropriate amounts of 10% Ca (OH)\textsubscript{2} were used in order to correct the pH at 7.6 using a small 2 L batch parallel test with 0.5 L of the original mixed digested material. The amount of Ca (OH)\textsubscript{2} needed to reach the pH 7.6 was measured step by step, and repeated every day for one week until the pH became stable.

Loading and feeding were done by subtracting (removing) from the vessels 1/20 of the content and replacing with same amount of fresh material, while the extracted part was mixed with the fresh material (1/2 each) before being used to feed the digesters. Biogas production was read in water columns and methane was quantified using a gas chromatograph Intersmat IGC 112M, coupled with a HP printer.

The following parameters were monitored: total solids (TS) and volatile solids (VS) using a programmable Nabertherm furnace, according to Greenberg et al. (1992). The pH was tested on a pH meter ORION Research Analyzer/model 407 A. Temperature was recorded on a normal standard (–10–100°C) thermometer. The small-scale test was done at the University of Gent and the large-scale tests were done at the University of Kinshasa, Congo.

Results
Start-up
After 27 days, the pH was still low (5.8–6.2) in all containers. This almost stopped the production of biogas. The correction of the pH was required. By adjusting the pH using 10% Ca (OH)\textsubscript{2} on day 53, the stability and optimum conditions for the methanogenic bacteria
were allowed to work, as can be seen from Figure 1, where the biogas production has reached 4–5.6 m³/m³ reactor.day, with a methane content of about 60–70% (Figure 2). This showed an improvement in biogas production, but still a low volumetric rate was observed when compared with the DRANCO (8 m³/m³ reactor.day). However, the experiment took place at mesophilic condition where optimum biogas production should be evaluated.

The pH was adjusted with Ca (OH)₂ from day 54 onwards. The loading rate applied in the digesters in order to maintain the biogas production was 4.1 kg VS/m³ reactor.day. The rate of product formation (volume of dry biogas or better methane produced) per unit time per unit reactor volume (m³ biogas/m³ reactor.day) was 4–5 m³ (1.2 m³/kg VS of fresh wastes).

**Discussion**

Methane reactors are usually operated under substrate-limiting conditions especially during start-up (Megaert and Verstraete, 1987). But start-up can be practised at substrate non-limiting conditions, which means that cells have an ample substrate supply so that they achieve effective cell yield close to the maximum cell yield value.

When starting an anaerobic digestion for solid waste, care should be taken to provide buffering media. Since most of the inoculum (Boue primeur) has to be supplied in high
amounts, its availability is a prerequisite. Otherwise, preference should be given to anaerobic sludge in order to start the anaerobic digestion in the conditions of low-income countries.

To buffer the pH, it may be possible to use some phosphate-rich fertilizer available in low tech-countries. If not, one can indeed use cow manure (10 kg/100 kg).

The pH has really influenced the methane formation. The correction of pH has increased rapidly the pH from acidic value to alkaline values (9.1).

The pH in liquid phase was always less (1–2 values). Therefore by rolling the vessels, this allows the pH correction and adjustment between the solid and liquid phases. As said by Megaert and Verstraete (1987), pH appears to be of paramount importance during start-up of high-rate reactors to avoid pH fluctuations.

The loading rate accurately describes the amount of feedstock required to provide the anaerobic bacteria sludge with a well adapted microbial population to degrade within a specified time (usually one day), and the units are kg VS or COD/LR.d.

Biogas production has been evaluated in solid state fermentation. The often-used criterion of gas production is 8 m$^3$ biogas/m$^3$ reactor.day for a loading rate of 21 kg COD/m$^3$ reactor.day (Van Meenen et al., 1988). This result is stated for thermophilic digesters. The results obtained in mesophilic conditions (4 m$^3$ biogas/m$^3$ reactor.day) can be considered as successful for mesophilic conditions. The maximum sustainable reaction rate (rate of substrate addition) or maximum organic loading rate ($OLR_{max}$) expressed in kg VS/m$^3$ reactor.d) gives an indication of biological performance in the digesters. In the conditions of our experiment, biogas production could be shortened to less than 2 months if the pH was corrected since the beginning. Indeed, the build up of anaerobic biomass up to levels of 30 g DW–1 and gas production rates of 15 L CH$_4$/L.d can be achieved in a matter of weeks (Megaert and Verstraete, 1987).

Mixing by rolling the vessels is thought to optimize the process of anaerobic digestion by enhancing interaction between cells and substrates and removing the inhibitory metabolic products from the cells (Chynoweth and Pullammanappallil, 1996).

Van Meenen et al. (1988) found, for the Dranco process, a stable operation on the MSW organic possible at 35–40°C at a loading rate of 17.2 kg COD/m$^3$ reactor.d. The same authors obtained a gas production rate of 6.2 m$^3$ biogas/m$^3$ reactor.day for mesophilic operation.

The extraction of the leachate by compression may be done in order to maintain the dry matter content in the digester, and make an anaerobic test for the leachate.

Care should be taken when one tries to use pig manure in anaerobic digestion of MSW waste. The proportion 1:10 may be inhibitory and toxic for methanogenic bacteria, which may not recover soon. Meanwhile, it can be proposed that one prepares an inoculum for dry anaerobic digestion by putting anaerobic sludge and cow manure, together with alkaline plants (Pistia stratiotes), into closed containers in order to have a readily available inoculum, for large-scale plant, in low-tech countries.

The use of a multistage system in such conditions can allow one to treat a daily amount of one ton solid waste and obtain a yield of 100 m$^3$ biogas. This corresponds to about 60 L kerosene and is estimated to cost 60 US$. The system can serve individual homes or industries in low-tech countries where chalk coal is overexploited and contributes to deforestation. Overall, the investment costs for anaerobic digestion are a factor of 1.2–1.5 higher than for aerobic composting. Nevertheless the recovery of energy (100–1,500 m$^3$ biogas per ton of biowaste) is an important factor, particularly in third-world countries (Verstraete et al., 2000). For that, its unique potential to become part of the Kyoto CO$_2$ and eco-balance negotiations must be timely and effectively expressed to society in general and to the political authorities who are involved in long-term environmental management and decision making, in particular in low-tech nations.
Conclusions
Ca (OH)$_2$ 10% used in waste in the proportion 1:80 (v/v) appears to be a good pH stabilizer when starting solid waste anaerobic digestion. This could allow the maintenance of pH at 7.5, subsequently followed by biogas production. A more concentrated solution may create an underpressure in the digesters and subsequently stop the biogas production. Therefore it is advisable in our type of work, to stabilize the pH of the fresh material maintained for one month using 10% Ca (OH)$_2$, 1:80 (v/v) and anaerobic sludge (1–2:10, v/v), in mesophilic conditions, and keep it for one month before starting to load the digester. Coupling the digesters in a multistage system allows the biogas production to be maintained at high level and may be of useful application in low-tech countries.

References