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Process performance and modelling of anaerobic digestion using source-sorted organic household waste

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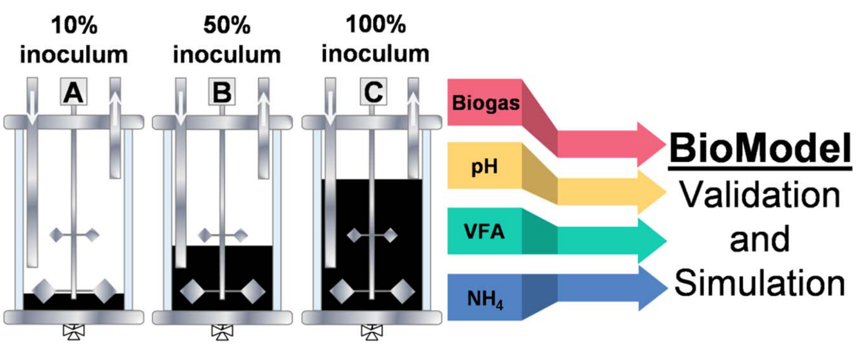
GRAPHICAL ABSTRACT



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ABSTRACT

Three distinctive start-up strategies of biogas reactors fed with source-sorted organic fraction of municipal solid waste were investigated to reveal the most reliable procedure for rapid process stabilization. Moreover, the experimental results were compared with mathematical modeling outputs. The initial inoculations to start-up the reactors were 10, 50 and 100% of the final working volume. While a constant feeding rate of 7.8 gVS/d was considered for the control reactor, the organic loading rate for fed-batch reactors with 10 and 50% inoculation was progressively increased during a period of 60 and 13 days, respectively. The results clearly demonstrated that an exponentially feeding strategy, considering 50% inoculation relative to final volume, can significantly decrease the alternatively prolonged period to reach steady conditions, as observed by high biogas and methane production rates. The combination of both experimental and modelling/simulation succeeded in optimizing the start-up process for anaerobic digestion of biopulp under mesophilic conditions.

1. Introduction

The surge in world population growth along with the dramatic rise in per capita consumption, caused by industrialization, increased living standards, and globalization, can be identified as the most important factors driving the increase in worldwide energy demand (Khoshnevisan et al., 2015; Rajaeifar et al., 2014). On the other hand, the raised public awareness of this increased energy demand and diminishing fossil resources, as well as the negative environmental pollutions resulted from the huge consumption of fossil origin fuels have pushed researchers to focus on renewable energy sources (Rajaeifar et al., 2014). Organic Fraction of Municipal Solid Waste (OFMSW) is

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among distinctive renewable sources showing a promising potential to recover energy through anaerobic digestion (AD) (Angelidaki et al., 2006b; Cabbai et al., 2013; Güelfo et al., 2010). Treating OFMSW through AD has drawn attention due to the low level of sludge generation, lower energy consumption, increased level of methane (CH_4) production, and the production of a nutrient rich fertilizer (Güelfo et al., 2010; Sonesson et al., 2000). Additionally, AD is a more environmentally friendly method compared with other waste management scenarios because it decreases greenhouse gas emissions (Tian et al., 2017).

Although benefiting from AD, biological treatment of OFMSW suffers from some drawbacks including the slow rate of the process and prone to inhibition due to imbalance between the volatile fatty acids (VFAs) and other precursor-producing bacteria and methanogenic archaea (Ahring et al., 1995; Goberna et al., 2015). The issue discussed is also more problematic when it comes to start-up stage because several parameters including type of inoculum, organic loading rate (OLR), pH, temperature, and hydraulic retention time (HRT) can deeply affect the stability of the process and consequentially, the biomethanation process as well as the kinetics of the first step of AD (i.e. hydrolysis). For instance, although in the literature an OLR between 2 and 6 gVS/L/d is typically found (Schnürer et al., 2017), setting-up the optimal initial OLR depends on various parameters as inoculum origin, the time between the collection of inoculum and the start-up of the process, and the temperature of the inoculum (Li et al., 2013; Mao et al., 2015). Setting-up the optimal initial OLR is also important especially during start-up periods because an increase in OLR is typically followed by a decrease in HRT, leading to improper degradation of a specific material under specific operating parameters (Schnürer et al., 2017).

The start-up stage of AD has gained considerable attention as the proper strategy to initiate the biological treatment of organic compounds can affect the stability of the overall process and consequently, the economic aspects (Garcia-Solano et al., 2016;Janke et al., 2016; Moset et al., 2014). An efficient start-up process would result in adopted microbial communities with higher level of tolerance to inhibition conditions. As reported by Palatsi et al. (2009)a well-established strategy based on feeding patterns can prevent the diverse effects caused by changes in operational conditions and enhance digester performance. Suwannoppadol et al. (2011) conducted a research on start-up of thermophilic anaerobic digestion with the turf fraction of MSW as inoculum. The researchers concluded that during the start-up period, the provision of high buffer capacity and slow stirring are crucial parameters for increased process efficiency.

The evaluation of start-up strategies can be performed using three types of reactor configurations. First, the batch experiments have been periodically employed to assess the highest cumulative biogas and methane yields of specific substrates and/or co-digestion process (Pavi et al., 2017). When a sufficient supply of carbon and nutrient is available, the batch configuration is suitable but “once feeding”, i.e., feeding the reactors once starting-up, is considered as a constraint for this type of reactor (Tian et al., 2017). Unless removed via biological mediated processes, all substrates, microorganisms, enzymes and products are accumulated in the reactors. Accumulation of inhibitory intermediates in homeostatic threshold concentrations can result in inhibited metabolic reactions within the reactors. Alternatively, fed-batch systems can replace batch reactors and benefit from continuous-flow feeding without fermentation broth removal, and most importantly the concentration of all compounds is kept at low level all the time compared to batch (Ding & Tan, 2006). However, some other challenges including difficulties in calculating growth rate and sterility issues can arise (Wechselberger et al., 2013). Continuous stirred tank reactors (CSTRs) appear as the third alternative offering a more stable condition while avoiding toxicant accumulation (Tian et al., 2017).

Overall, for a successful start-up, parameters such as inoculum origin and composition as well as feeding strategy should be carefully designed to avoid accumulation of intermediate products such as VFAs and hydrogen which can inhibit the methanogenesis step (Angelidaki et al., 2006b). Thus, it is of major importance to address the challenges aforementioned in order to guarantee an optimal and stable process operation. One way to investigate start-up procedures is with the aid of reliable mathematical models so that experimental effort, cost and risk are minimized. Mathematical models can provide insights into understanding and analyzing important aspects such as inhibition pathways, changes in microbial population dynamics and synergistic effects (Angelidaki et al., 1999). Hence, optimized policies for both start-up and its following operation of AD reactors can be revealed leading to improved process sustainability.

Although many researches are focusing on either the experimental part of start-up processes or modelling of AD reactors, only limited attention has been paid to the combination of both experimental and modelling/simulation aspects treating processed OFMSW (denoted as “biopulp”). Batch, fed-batch and CSTRs were set up to define the methane potential and optimal start up process for biopulp under mesophilic conditions. Regarding the mathematical model and process simulation, the bioconversion model developed by Angelidaki et al. (1999) and Kovalovszki et al. (2017) was used as starting point to investigate the start-up strategies treating biopulp. Then, model results were validated through the corresponding lab-scale experiments.

2. Materials and methods

2.1. Characterization of inoculum and substrate

The inoculum used in the current study was supplied from Hashøj full-scale biogas plant (Sealand, Denmark), co-digesting livestock slurries and food industrial wastes under mesophilic conditions. The characteristics of the inoculum are presented in Table 1.

The substrate used was source-sorted organic fraction of municipal solid waste (SS-OFMSW) undergone biopulping process for increased biodegradability by Gemidan Ecogi A/S. The total solid (TS) and volatile solid (VS) of concentrated substrate were 128.05 ± 0.74 gTS/kg

Table 1
Characteristics of inoculum and substrate.

Parameter	Unit	Inoculum (stdev)	Biopulp (stdev)
TS	g/kg	38.61(0.34)	60.52(0.52)
VS	g/kg	24.07(0.35)	52.11(0.55)
pH		8.38	3.90
TAN	gNH_4-N/L	3.80(0.01)	0.40(0.01)
FAN	gNH_3-N/L	0.82(0.01)	–
TKN	gTKN/L	5.38(0.25)	1.70(0.03)
TFA	g/L	0.16(0.08)	3.92(0.38)
COD	g/L	nm	83.95(3.01)
Total Carbohydrate	g/L	nm	31.55(1.58)
Total Protein	g/L	nm	9.08(0.45)
Total Lipid	g/L	nm	7.87(0.39)
Acetate	g/L	0.14(0.05)	3.10(0.09)
Propionate	g/L	0.03(0.01)	0.24(0.01)
Hexanol	g/L	0.00(0.01)	0.11(0.01)
Ethanol	g/L	0.02(0.01)	3.83(0.20)
Butyrate	g/L	0.00(0.01)	0.20(0.01)
Isobutyrate	g/L	0.03(0.01)	0.01(0.01)
Al	g/kgTS	nm	1.15(0.27)
Ca	g/kgTS	nm	20.46(1.73)
Cu	g/kgTS	nm	0.02(0.00)
K	g/kgTS	nm	9.80(0.77)
Mg	g/kgTS	nm	1.96(0.11)
Mn	g/kgTS	nm	0.15(0.01)
Na	g/kgTS	nm	8.19(0.47)
P	g/kgTS	nm	2.73(0.16)
S	g/kgTS	nm	2.66(0.15)
Sr	g/kgTS	nm	0.09(0.01)
Fe	g/kgTS	nm	1.36(0.01)
Ba	g/kgTS	nm	0.04(0.01)

nm: not measured.