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Impact of physical pre-treatment of source-sorted organic fraction of municipal solid waste on greenhouse-gas emissions and the economy in a Swedish anaerobic digestion system

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ABSTRACT

Several methods for physical pre-treatments of source sorted organic fraction of municipal solid waste (SSOFMSW) before for anaerobic digestion (AD) are available, with the common feature that they generate a homogeneous *slurry* for AD and a dry *refuse* fraction for incineration. The selection of efficient methods relies on improved understanding of how the pre-treatment impacts on the separation and on the slurry's AD. The aim of this study was to evaluate the impact of the performance of physical pre-treatment of SSOFMSW on greenhouse-gas (GHG) emissions and on the economy of an AD system including a biogas plant with supplementary systems for heat and power production in Sweden. Based on the performance of selected Swedish facilities, as well as chemical analyses and BMP tests of slurry and refuse, the computer-based evaluation tool ORWARE was improved as to accurately describe mass flows through the physical pre-treatment and anaerobic degradation. The environmental and economic performance of the evaluated system was influenced by the TS concentration in the slurry, as well as the distribution of incoming solids between slurry and refuse. The focus to improve the efficiency of these systems should primarily be directed towards minimising the water addition in the pre-treatment provided that this slurry can still be efficiently digested. Second, the amount of refuse should be minimised, while keeping a good quality of the slurry. Electricity use/generation has high impact on GHG emissions and the results of the study are sensitive to assumptions of marginal electricity and of electricity use in the pre-treatment.

1. Introduction

Waste management policies and practices in Sweden are prioritized following the waste hierarchy of the European Union's Directive 2008/98/EC: prevention, preparation for reuse, recycling, other recovery, notably of energy, and disposal. In this context, the *Swedish National Environmental Quality Objectives* (Ministry of the Environment, 2013) are currently directed towards separate collection of food waste from households and restaurants, with the specific goal to collect 50% and to treat 40% of the collected waste with recovery of both energy and nutrients by 2018.

Anaerobic digestion (AD) is known to play a key role in the recovery of energy and nutrients from organic wastes, especially in the case of the source-sorted organic fraction of municipal solid waste (SSOFMSW), which has high anaerobic biodegradability (Zhang et al., 2007). Nevertheless, the heterogeneous nature of SSOFMSW with the common occurrence of non-degradable components makes physical pre-treatment, including separation and homogenisation, necessary before AD. In Sweden, the SSOFMSW is often pre-treated as to obtain a homogeneous *slurry* that can be anaerobically treated in continuously stirred tank reactors (CSTR). Impurities and large particles end up in a dry *refuse* fraction, which is normally incinerated.

Several methods for physical pre-treatments of SSOFMSW are available and their performance have been the subject of numerous investigations (Bernstad et al., 2013; Carlsson et al., 2010; Fransson et al., 2013; Hansen et al., 2007). Important physical pre-treatment performance indicators include SSOFMSW dilution level, the mass distribution between slurry and refuse, quality of slurry, energy input and maintenance costs. Efforts have been

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made to establish correlations between pre-treatment methods and performance indicators. In general, some techniques, such as screw presses, are associated with a good selectivity of separation resulting in a highly degradable slurry with little contaminants, but directing a larger fraction of the incoming waste into the refuse (Bernstad et al., 2013; Hansen et al., 2007). Nevertheless, other techniques that result in less refuse are often associated with less selective separation and the risk of impurities entering the AD process. Thus, improved SSOFMSW management relies on a better understanding of how the physical pre-treatment impacts on the separation and the slurry's AD so that efficient methods can be selected (Bernstad et al., 2013).

The improvement in SSOFMSW management from a more holistic perspective, however, depends not only on the relation between efficiency of physical pre-treatment and biomethane yields from the slurry, but also on the overall environmental and economic performance of the pre-treatment-AD system as a whole. Generally, the environmental impacts and financial costs of waste management are related to processes outside the waste management system, such as generation of district heating, electricity, vehicle fuel and fertilizer (Eriksson et al., 2005), and they must therefore be analysed in well-defined systems that are more comprehensive than the pre-treatment-biogas process chain. Life cycle assessment (LCA) has been commonly used to study different options for collection and treatment of SSOFMSW and to establish the relationship between performance parameters of SSOFMSW AD and associated environmental and/or economic impacts. For example, different techniques for separate collection of household food waste with subsequent AD of the organic fraction were compared by Bernstad and la Cour Jansen (2012) using the ISO LCA approach (ISO 2006a,b), focusing on the impact categories of eutrophication potential (EP), acidification potential (AP), global warming potential (GWP) and primary energy use (PEU). A sensitivity analysis revealed that the losses of organic material in the refuse from the physical pre-treatment had a large impact on the results. The complexity of the evaluated systems often necessitates the use of computer-based models, of which for instance EASEWASTE (Christensen et al., 2007) and ORWARE (Eriksson et al., 2005) have been used for LCA in municipal solid waste management. ORWARE has also been used in a comparative economic evaluation of different waste treatment options, in which case AD of food waste was found to be potentially economically competitive (Eriksson et al., 2014). Notwithstanding this, the composition of SSOFMSW as defined in the ORWARE model and its fate in pre-treatment and AD may require further development to achieve a better process description (Sonesson and Jönsson, 1996).

The aim of this study was to evaluate the impact of the performance of physical pre-treatment of SSOFMSW on the environmental impact categories of energy use and GWP, here expressed as greenhouse-gas (GHG) emissions and on the economy of an AD system including a biogas plant with supplementary systems for heat and power production in Sweden. Emphasis was given to analysing the system from a holistic approach as to provide insights into the process performance useful for biogas plant stakeholders. A new approach is presented for simulating process performance with an improved version of ORWARE by characterising the different components of SSOFMSW and describing mass flows through the physical pre-treatment and anaerobic degradation.

2. Method

2.1. Overall approach

The study includes both experimental work to evaluate influence of pre-treatment on SSOFMSW mass transfer, and an environmental and economic systems analysis, where obtained data is used as input. Based on four selected Swedish facilities with physical pre-treatment processes treating SSOFMSW (Table 1), performance data were first used for preliminary assessment of mass balances of the treatment processes with ORWARE. Due to lack of complete data for describing the feedstock and its fate in AD in ORWARE, the need for further characterisation was identified. Samples of slurry and refuse were collected and analysed for components relevant for the modelling of pre-treatment and AD. In addition, BMP tests were conducted on the samples to validate the outcomes of AD modelling. The model was then modified and the updated model was used to evaluate pre-treatment performance based on system scenarios relevant for Swedish conditions.

2.2. Experimental procedures

2.2.1. Collection of refuse and slurry

Composite slurry samples were collected from three facilities (A–C) and refuse samples from two facilities (A and B), respectively. Composite samples of 15 kg were obtained by mixing equal proportions of 3–4 grab samples collected during a working day. Samples were either transported to the laboratory within one hour or within 24 h after transportation in a refrigerated truck. Upon arrival to the laboratory, the samples were stored at 4 °C until preparation, which took place within 24 h.

2.2.2. BMP tests

Sub-samples of slurry for BMP-tests were taken out without further treatment. Refuse samples were subjected to manual sorting where larger pieces of glass, stone, bones and metal were removed. The amount of removed particles was 5.9% of the wet weight in A and 2.5% of wet weight in B. Larger particles were cut down to a particle size of about <20 mm. Sorted sub-samples of refuse for BMP-tests were then taken out without further treatment.

BMP tests were performed and reported following the protocol suggested by Angelidaki et al. (2009) with the exception that no nutrient/buffer media was used and pure nitrogen gas was used as flushing gas. The inoculum was digestate collected from a co-digestion plant treating SSOFMSW, manure and industrial waste (facility B). The inoculum to substrate ratio was 2:1 on a VS basis and the loaded substrate concentration was 2.2 g VS/L after dilution with tap water. Controls were prepared containing only inoculum and tap water and the activity of the inoculum was tested with microgranular cellulose (Sigma–Aldrich C6413). 300 ml of substrate/inoculum/water mixture was added to 1000 ml gas tight test bottles, and the head space purged with N_2 after which the bottles were sealed and incubated at 37 °C. Controls and tests were performed with five replicates. The methane concentration was measured by gas chromatography as described by Angelidaki et al. (2009). The gas chromatograph used was a Perkin Elmer Clarus 480 with a packed column (2.5 m, 3.2 mm, Porapak, 50–80 mesh), with helium as the carrier gas and equipped with a thermal conductivity detector. The injector temperature was 80 °C, column temperature 60 °C and detector temperature 150 °C. Samples of 0.2 ml were collected regularly from the headspace of the BMP bottles with a gas tight syringe and the peak areas of the over-pressurised samples were related to those of a 0.2 ml sample of a standard gas mixture (75% CH_4, 15% CO_2 and 10% N_2) collected at atmospheric pressure. The total volume of methane in the headspace at the time of sampling was then calculated based on the molar concentrations measured and the ideal gas law. Gas production from the inoculum was subtracted from the total gas production in the test bottles. BMP was expressed as the cumulative amount of methane produced in STP conditions (0 °C, 1 atm) after a plateau in methane production was reached relative to the amount of VS introduced.