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Comparison of pasteurization and integrated thermophilic sanitation at a full-scale biogas plant – Heat demand and biogas production

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ABSTRACT

Sanitation is required for biogas plants handling slaughterhouse and food waste according to EU legislation. The standard method is pasteurization at 70 °C for 60 min, but integrated thermophilic sanitation (ITS), requiring 52 °C for 10 h in the digester, has been approved by the Swedish Board of Agriculture. This work compares pasteurization and ITS regarding heat demand and biogas production, using a full-scale plant in Uppsala, Sweden, as a case study. The plant currently uses pasteurization and thermophilic (52 °C) digestion. The impact of pasteurization on biogas production and process performance was examined at laboratory-scale. The heat demand for pasteurization was surveyed at the full-scale plant, while for ITS a process design was developed and the heat demand was theoretically calculated. The results showed that pasteurization had no significant effect on process performance or biogas production. The heat demand of pasteurization was measured to be 1.92 ± 0.29 MJ (kg VS)$^{-1}$ (64.7 kWh t^{-1}), while ITS was calculated to require 1.04 MJ (kg VS)$^{-1}$ (35.1 kWh t^{-1}). This represented 9% and 5% of biogas energy production, respectively. Changing sanitation method to ITS would hence reduce the heat demand at the plant by 46%, corresponding to annual savings of 4380 GJ (1.22 GWh).

1. Introduction

Anaerobic digestion has attracted increasing interest in recent years due to the EU target of 20% renewable energy in the total energy system, including 10% in the transport sector, by 2020 [1]. As a consequence, biogas production is increasing in Europe. In Sweden, biogas production increased by 24% from 2005 to 2012 [2], with 32% of Swedish biogas originating from co-digestion plants, mostly connected to municipal waste treatment. In total, there are 14 mesophilic and seven thermophilic co-digestion plants in Sweden [2]. One of the keys to further growth of the biogas sector is cost savings through improved energy efficiency [3], which can be achieved by higher methane yield and/or lower process energy demand.

Category 3 ABP (animal by-products), for example slaughterhouse waste and food waste [4], require sanitation under EU law in order to reduce the amount of pathogens and prevent the spread of infections [5]. The standard method is pasteurization, which involves keeping the material at 70 °C for at least 60 min. However, EU legislation allows Member States to approve alternative methods as long as it can be proven that the risks regarding pathogens are satisfactorily reduced [5]. The Swedish Board of Agriculture has approved sanitation through thermophilic digestion with a guaranteed retention time of 10 h in the digester at 52 °C and a minimum HRT (hydraulic retention time) of seven days [6]. The method is called ITS (integrated thermophilic sanitation) and gives a similar reduction in pathogenic indicator organisms to pasteurization [7]. At least one co-digestion plant in Sweden currently applies ITS [8].

The biogas plant Kungsängens gård, owned by Uppsala Vatten och Avfall AB in Uppsala, Sweden, has been in operation since 1996. In 2012, 25,200 t of waste comprising a mixture of the SS-OFMSW (source-sorted organic fraction of municipal solid waste) (about 82 wt%), food waste (about 3 wt%) and slaughterhouse waste (about 15 wt%) were digested under thermophilic conditions (52 °C) at the plant, producing 4.4 Mm$_n^3$ (1 atm, 0 °C) of biogas. The biogas is upgraded by water scrubbing and sold as vehicle fuel. The current

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Nomenclature

Abbreviations

TS	total solids [%]
VS	volatile solids [%]
OLR	organic loading rate [kg VS m^{-3} d^{-1}]
HRT	hydraulic retention time [d]
VFA	volatile fatty acids [g L^{-1}]
ITS	integrated thermophilic sanitation
LHV	lower heating value
D1/2	digester 1 or 2 at the full-scale plant

Variables and parameters

$K_{past/ITS}$	heat demand fraction of total biogas energy output for pasteurization (past) or ITS [%]
$e_{lab,past/non\text{-}past}$	specific energy output for the lab reactors receiving pasteurized (past) or non-pasteurized (non-past) substrate [MJ (kg VS)$^{-1}$]
$e_{prod,past/ITS}$	specific biogas energy output for the pasteurization (past) or ITS system [MJ (kg VS)$^{-1}$]
e_D	specific heat demand for heating the digesters [MJ (kg VS)$^{-1}$]
e_{past}	specific heat demand for pasteurization [MJ (kg VS)$^{-1}$]
$e_{demand,past}$	specific heat demand for the pasteurization system, $e_d + e_{past}$ [MJ (kg VS)$^{-1}$]
$e_{demand,ITS}$	specific heat demand for ITS [MJ (kg VS)$^{-1}$]
E_D	daily heat demand for heating the digesters [MJ d^{-1}]
E_{biogas}	daily boiler biogas energy consumption [MJ d^{-1}]
E_{past}	daily pasteurization energy demand [MJ d^{-1}]
E_{heat}	daily heat demand of the hot water system (heating the whole premises including the digesters) [MJ d^{-1}]
V_{biogas}	daily biogas production [m^3 d^{-1}]
V_{boiler}	daily boiler biogas consumption [m_n^3 d^{-1}]
c_{CH4}	methane content of biogas [%]
H_{CH4}	lower heating value of methane [35.9 MJ m_n^{-3}]
m_{sub}	daily amount of substrate added [kg d^{-1}]
η	boiler efficiency [%]
$\vartheta'/''$	temperature difference between the media before (') or after ('') the counterflow heat exchanger [K]
$t_{w/c1}$	intake temperature of warm (w) or cold (c) medium [K]
$t_{w/c2}$	return temperature of warm (w) or cold (c) medium [K]
$\dot{m}_{w/c}$	mass flow of warm (w) or cold (c) medium [kg s^{-1}]
k	heat transfer coefficient [W m^{-2} K^{-1}]
A	heat exchanger area [m^2]
$c_{w/k}$	specific heat capacity of warm (w) or cold (c) medium [J kg^{-1} K^{-1}]

sanitation method applied is pasteurization, using steam produced by a biogas boiler. However, as the process is thermophilic, it would be possible to implement ITS by ensuring that the substrate stays in the digesters for at least 10 h (HRT is 30–35 d).

Coultry et al. reported a higher energy demand for a low-temperature sanitation option (60 °C for 48 h) compared to pasteurization [9]. However, ITS is integrated with the anaerobic digestion and not performed in an external vessel, indicating that heat losses and demand could be reduced compared to pasteurization. This would decrease the internal biogas demand and increase the amount of biogas available for upgrading and sale. Nevertheless, the pasteurization process has been shown to increase the methane yield in a number of studies [10–15]. Thermal pre-treatment increases substrate solubility and accessibility for micro-organisms, but the effect depends on the substrates and temperatures used. In some studies, the methane yield was unaffected by the pre-treatment [14,16–18] and in others the methane yield was negatively affected due to the formation of complex and toxic compounds [12,15]. Therefore, it is important to study the process performance and the resulting methane yield for the digestion of pasteurized and non-pasteurized substrate related to a particular plant before changing sanitation methods.

The aim of this work was to compare pasteurization with ITS regarding heat demand and biogas production. The methane yield from pasteurized and non-pasteurized substrate was related to the heat demands of the sanitation methods in order to evaluate the feasibility of changing sanitation methods from pasteurization to ITS at the full-scale plant.

2. Materials and methods

The specific biogas production and corresponding energy yield when digesting pasteurized and non-pasteurized substrate were studied in laboratory-scale digesters. The heat demand for pasteurization was surveyed through data collection at the full-scale plant. For ITS, the heat demand was theoretically calculated based on a process design developed for the full-scale plant. The heat demands were related to the biogas energy yields and the two sanitation options were compared.

2.1. Laboratory-scale processes

Two identical laboratory-scale (5 L active volume) tank reactors (Dolly, Belach Bioteknik AB, Stockholm, Sweden), equipped with automatic stirring, temperature regulation (electric heating band) and gas flow metering [19], were semi-continuously operated at thermophilic temperature (52 °C). Inoculum and substrate were collected from the full-scale biogas plant. The substrate (TS (total solids) 15.8% and VS (volatile solids) 13.9% of wet weight) was collected on one occasion, divided into 20-kg portions and stored at −20 °C until use. Iron chloride combined with the trace elements Co, W, Ni and Se (Kemira BDP-865, Kemira Kemi AB, Helsingborg, Sweden) is used at the full-scale plant, and was therefore added to the substrate in the same proportions for the laboratory experiments (2.5 mL kg^{-1}). The two reactors, GC1 and GC2, were fed once a day, six days a week. The daily OLR (organic loading rate) was 3.0 g VS L^{-1} d^{-1} and the HRT was 35 d, which are similar to the conditions in the full-scale plant.

The reactors were started within a few hours after the collection of the inoculum and were initially fed with non-pasteurized substrate for 14 d. When the daily gas production was similar in both reactors, pasteurized substrate was introduced to GC2, while GC1 continued to receive non-pasteurized substrate. For pasteurization, the daily feed of substrate was heated in a water bath and kept at 72–74 °C for 60 min. After the start-up period, the reactors were operated for 84 d, i.e. 2.8 HRT.

2.1.1. Sampling and analytical methods

Biogas production was automatically and continuously measured by a volumetric water displacement gas meter (Belach Bioteknik AB, Stockholm, Sweden) and logged on a daily basis. For calibration, the gas volume was collected in gastight bags and