Waste Management 47 (2016) 21–27

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Co-digestion of manure and industrial waste – The effects of trace element addition

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ARTICLE INFO

Article history:
Available online 23 March 2015

Keywords:
Biogas
Co-digestion
Manure
Trace element
Cobalt
Nickel

ABSTRACT

Manure is one of the most common substrates for biogas production. Manure from dairy- and swine animals are often considered to stabilize the biogas process by contributing nutrients and trace elements needed for the biogas process. In this study two lab-scale reactors were used to evaluate the effects of trace element addition during co-digestion of manure from swine- and dairy animals with industrial waste. The substrate used contained high background concentrations of both cobalt and nickel, which are considered to be the most important trace elements. In the reactor receiving additional trace elements, the volatile fatty acids (VFA) concentration was 89% lower than in the control reactor. The lower VFA concentration contributed to a more digested digestate, and thus lower methane emissions in the subsequent storage. Also, the biogas production rate increased with 24% and the biogas production yield with 10%, both as a result of the additional trace elements at high organic loading rates. All in all, even though 50% of the feedstock consisted of manure, trace element addition resulted in multiple positive effects and a more reliable process with stable and high yield.

1. Introduction

The worldwide biogas boom will continue in the coming years and the tendency to produce renewable energy goes hand in hand with the fast growth of the biogas industry (Döing et al., 2012). Hence, Döing et al. (2012) predicts that the numbers of biogas plants are expected to grow from 9700 (in 2012) up to 13500 (in 2016). Most of the biogas plants are located in Europe, and 75% of the European biogas plants are located in Germany (Döing et al., 2012). The main part of the German plants is fed with mostly manure in a mix with agricultural residues. In a review of Nasir et al. (2012) different manure types were compared with respect to methane yield. Typical methane yield from cattle manure was 0.20 $m^3\ kg^{-1}\ VS^{-1}$ while swine manure had a methane yield of 0.30 $m^3\ kg^{-1}\ VS^{-1}$ (Nasir et al., 2012). These methane yields are lower compared to anaerobic digestion of high value wastes such as slaughterhouse waste 0.50 $m^3\ kg^{-1}\ VS^{-1}$ (Nordell et al., 2013) and food waste 0.35–0.50 $m^3\ kg^{-1}\ VS^{-1}$ (El-Mashad and Zhang, 2010; Moestedt et al., 2014). As the German biogas market is in a mature stage, the need for repowering increases. Biogas output can be increased through optimization of the biological process, which can increase the efficiency of already existing plants. The German Biogas Association expects repowering to considerably exceed the construction of new plants in the coming years (Döing et al., 2012).

To improve the capacity of a biogas plant and create more favorable conditions for the microorganisms present in the digester, addition of trace elements such as cobalt and nickel may be applied (Jarvis et al., 1997; Kida et al., 2001; Pobeheim et al., 2010; Pobeheim et al., 2011; Schattauer et al., 2011). Cobalt is for example required in the vitamin B_{12} while nickel is required in F_{430}, both co-factors are essential by microorganisms involved in methanogenesis (Gottschalk, 1986; Kida et al., 2001). Several studies dealing with substrates such as slaughterhouse waste, thin stillage, grass-clover and food waste have shown that deficiency of trace elements such as cobalt may result in accumulation of volatile fatty acids (VFA) and sometimes even to decreased biogas yield (Bayr et al., 2012; Gustavsson et al., 2011; Jarvis et al., 1997; Kim et al., 2002; Lebuhn et al., 2008; Nordell et al., 2012). However, the effect of adding trace elements may depend on the bio-availability of these in the existing environment (Jansen et al., 2007). In reactor conditions with high levels of hydrogen sulfide, trace elements may be precipitated as insoluble metal sulfides, which

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http://dx.doi.org/10.1016/j.wasman.2015.02.032
0956-053X/

may result in deficiency of bio-available trace elements despite the addition (Gustavsson, 2012; Jansen et al., 2007). The typical concentration of trace elements (cobalt and nickel) added varies from 0.2 mg kg^{-1} to 0.5 mg kg^{-1} (Bayr et al., 2012; Ek et al., 2011; Gustavsson et al., 2011; Jarvis et al., 1997; Karlsson et al., 2012; Kida et al., 2001; Kim et al., 2002; Lebuhn et al., 2008; Moestedt et al., 2014; Nordell et al., 2012).

By combining addition of trace elements with addition of iron and acid (known as BDP, Kemira Kemi AB, Sweden), combined effects on the anaerobic digestion can be achieved simultaneously, e.g., avoiding H_2S toxicity by precipitation with $Fe^{2+/3+}$ (Wang and Banks, 2006) and decreased ammonia (NH_3) concentration (Ejlertsson, 2006; Ek et al., 2011; Moestedt et al., 2013). Hence, the digester performance is optimized through improvement of the complex interplay between biology and chemistry, increasing bio-availability of the trace elements. Kemira BDP has successfully been used at several biogas plants which mainly treats protein and fat rich substrates such as slaughterhouse waste (Ek et al., 2011; Nilsson et al., 2012).

The general perspective within the biogas industry is when manure is the dominant feedstock, the microorganisms will be provided with necessary vitamins and trace elements, such as nickel and cobalt, from the inherent concentration in the manure (Westerholm et al., 2012). Manure from cow and pigs are, if not being processed in an anaerobic digester, normally used as fertilizer without any treatment. By using manure for biogas production, the remaining carbon within the manure can be converted into biogas and simultaneously more nitrogen is released as ammonium, which results in a digestate with a higher concentration of ammonium, and is suitable as bio-fertilizer on farming land (Cantrell et al., 2008; Martin and Eklund, 2011).

The aim of this experiment was thus to evaluate the effects of trace element addition when manure from swine- and dairy animals were co-digested with residual fat, organic fraction from municipal solid waste (OFMSW), slaughterhouse waste and residual sludge. The substrate mixture was collected from real-life condition from a full-scale biogas plant in Sweden. In 2013 the full-scale plant ran at an organic loading rate of 2.4 kg V S m^{-3} d^{-1} with an annual bio-methane production of 24 GW h, the digestate is used as bio-fertilizer on farming land and the bio-methane is upgraded to ⩾97% of methane and delivered to the gas grid.

2. Material and methods

2.1. Experimental setup

Two continuously stirred tank reactors (CSTR) (Nordell et al., 2011) were used to evaluate the effects of trace element addition (Fig. 1). The 1st CSTR was used as control reactor where only iron (Fe^{2+}/Fe^{3+}) and acid (HCl) was supplied while the 2nd CSTR was used as an experimental reactor where iron (Fe^{2+}/Fe^{3+}) and acid (HCl) based trace element formulation; BDP-849 (Kemira Kemi AB, Sweden) was supplied (Fig. 1). The reactors were fed semi-continuously (fed once a day) with a substrate mixture consisting of dairy-, swine manure and industrial waste. The CSTRs working volume was 8 L and the headspace was set to 4 L to enable loading of the reactors even if heavy foaming should occur. The CSTRs had special features to prevent air from entering the reactors while sampling and feeding, and a volume adjustment function to favor a representative sampling (Nordell et al., 2011). The digesters were stirred with a mechanical stirrer (WVR, Sweden) and electrical motor (Heidolph, Germany) with a rate of 100–200 rpm.

2.2. Substrate and inoculum characteristics

Substrate was collected in sufficient volumes to last for the whole experimental period from the substrate mixing tank at a full-scale biogas plant in Sweden treating manure and industrial waste; the substrate was pasteurized (70 °C, 1 h) before freezing (−18 °C). The average composition (distribution) of the substrate mixture was (w/w): pig manure (30%), cow manure (18%), organic fraction of municipal solid waste (OFMSW, 19%), residual sludge (19%), slaughterhouse waste (12%) and residual fat (2%) (Fig. 2). Thus, 47% of the feedstock consisted of manure and 53% of industrial organic waste. Inoculum (adapted to the temperature 39 °C) was collected from the same biogas plant as the substrate was collected from to have an inoculum with microorganisms adapted to this particular substrate mixture. The inoculum was adapted to low hydrogen sulfide concentrations since iron chloride was continuously supplied to the process to suppress high concentrations of hydrogen sulfide. Chemical analysis and characteristics of the substrate mixture (distribution in Fig. 2) and inoculum are presented in Table 1.

2.3. Process additive (trace element formulation)

The trace element solution (Kemira BDP-849) contained: Fe (9%), Co (<100 μg L^{-1}), Ni (<100 μg L^{-1}), Se (<100 μg L^{-1}) and W (<100 μg L^{-1}). The amount of the trace element solution (BDP-849, Kemira Kemi AB, Sweden) that was added to the experimental reactor was made to in theory result in an additional cobalt and nickel concentration in the digestate of approximately 0.2 mg kg^{-1}. The concentration of trace element added was based on a literature review (Bayr et al., 2012; Ek et al., 2011; Gustavsson et al., 2011; Jarvis et al., 1997; Karlsson et al., 2012; Kida et al., 2001; Kim et al., 2002; Lebuhn et al., 2008; Moestedt et al., 2014; Nordell et al., 2012)

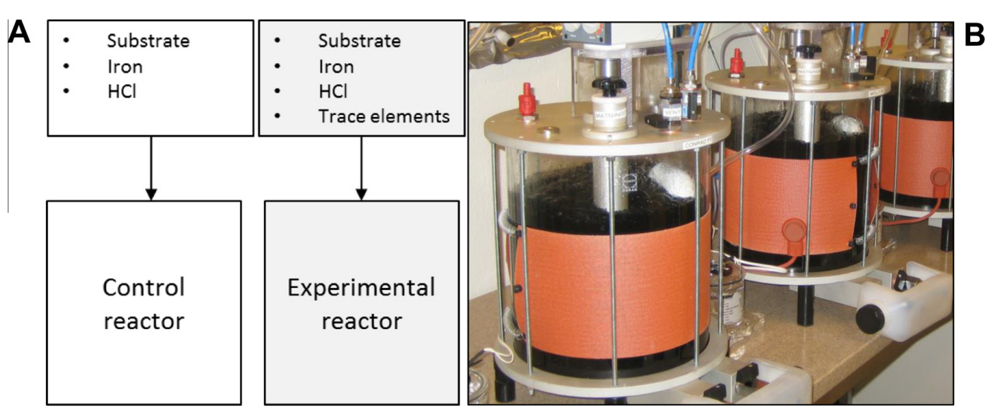

Fig. 1. (A) Schematic sketch of the experimental setup. (B) The patented lab-scale CSTR that was used in the experiment.