Applied Energy 179 (2016) 124–135

Contents lists available at ScienceDirect

Applied Energy

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

Biogas production through syntrophic acetate oxidation and deliberate operating strategies for improved digester performance

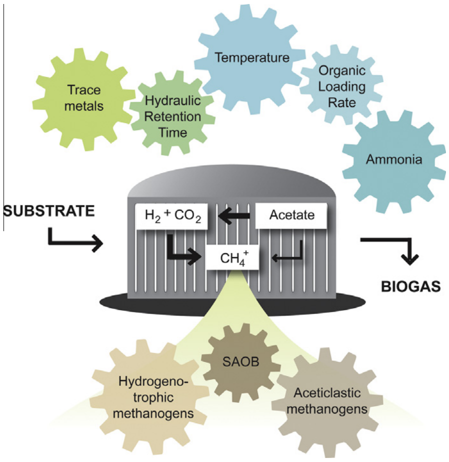
Maria Westerholm [a,*], Jan Moestedt [b], Anna Schnürer [a]

[a] Department of Microbiology, Swedish University of Agricultural Sciences, Uppsala BioCenter, Box 7025, SE-750 07 Uppsala, Sweden
[b] Department of Biogas R & D, Tekniska Verken i Linköping AB (publ.), Box 1500, SE-581 15 Linköping, Sweden

HIGHLIGHTS

- Syntrophic acetate oxidation (SAO) dominates in ammonia-adapted biogas processes.
- SAO bacteria compete for acetate and depend on their methanogenic partner.
- Syntrophic acetate oxidisers are present under a wide range of operating conditions.
- Ammonia, acetate, temperature, retention time and trace elements influence SAO.
- Awareness of SAO enables strategies for process optimisation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 January 2016
Received in revised form 1 June 2016
Accepted 17 June 2016

Keywords:
Syntrophic acetate oxidising bacteria
Methanogens
Ammonia inhibition
Operational parameters
Trace metals
Temperature

ABSTRACT

Anaerobic degradation of protein-rich materials has high methane potential and produces nutrient-rich residue, but requires strategies to avoid ammonia inhibition. A well-adapted process can cope with substantially higher ammonia levels than an unadapted process and analyses of pathways for methanisation of acetate, combined with determination of microbial community structure, strongly indicate that this is due to a significant contribution of syntrophic acetate oxidation. The microorganisms involved in syntrophic acetate oxidation thus most likely occupy a unique niche and play an important role in methane formation. This review summarises current insight of syntrophic acetate oxidising microorganisms, their presence and the detection of novel species and relate these observations with operating conditions of the biogas processes in order to explore contributing factors for development of an ammonia-tolerant microbial community that efficiently degrades acetate through the syntrophic pathway. Besides high ammonia level, acetate concentration, temperature and methanogenic community structure are considered in this review as likely factors that shape and influence SAO-mediated microbial ecosystems. The

---

Abbreviations: VFA, volatile fatty acids; SAO, syntrophic acetate oxidation; SAOB, syntrophic acetate-oxidising bacteria; HRT, hydraulic retention time; qPCR, quantitative PCR; FTHFS, formyl tetrahydrofolate synthetase; DNA-SIP, nucleic acid-based stable carbon isotopic probing; MAR-FISH, microautoradiography-fluorescence in situ hybridisation; TAN, total ammoniacal nitrogen; OLR, organic loading rate; VS, volatile solid; COD, chemical oxygen demand; RT-PCR, reverse transcription PCR; *mcrA*, methyl coenzyme-M reductase; T-RFLP, terminal restriction fragment length polymorphism; NanoSIMS, nanometer scale secondary-ion mass spectrometry; ARISA, automated ribosomal intergenic spacer analysis; DIET, direct interspecies electron transfer; UASB, upflow anaerobic sludge blanket.

[*] Corresponding author.

E-mail addresses: Maria.Westerholm@slu.se (M. Westerholm), Anna.Schnurer@slu.se (J. Moestedt), Jan.Moestedt@tekniskaverken.se (A. Schnürer).

http://dx.doi.org/10.1016/j.apenergy.2016.06.061
0306-2619/

main purpose of this review is to facilitate process optimisation through considering the activity and growth of this key microbial community.

Contents

1. Introduction

Along with increased energy efficiency, substitution of fossil fuel-derived energy with renewable sources is crucial in achieving the goal of reduced emissions of anthropogenic greenhouse gases. Biogas produced through anaerobic degradation of organic residues has good potential in climate change mitigation and also involves indirect environmental benefits such as reduced emissions of air pollutants and ammonia. European biogas production is experiencing high growth at the moment [1], increasing the demand for establishment of new production plants, but also process optimisation to increase energy output in existing plants.

Protein-rich substrates are of interest for commercial biogas production due to the relatively high methane yield potential [2,3] and the high level of plant-available ammonium (NH_4^+-N) in the residue. This residue can be applied to arable land as fertiliser, which reduces the need for production of mineral fertiliser, contributes to recirculation of nutrients and improves soil quality. A high content of ammonium considerably increases the value of the residue and thereby enhances profits for the biogas plant. However, due to the high amounts of ammonium in equilibrium with ammonia, the anaerobic degradation of protein-rich substrates is often associated with process instability, indicated by reduced biogas production and/or methane content, fluctuations in pH and alkalinity, and accumulation of volatile fatty acids (VFA) [4]. Protein-rich substrates are also a common source for formation of sulphide [5,6], which is not only toxic for various microbial populations but also forms complexes with metals, resulting in decreased bioavailability of trace elements essential for microbial activity [7]. However, the positive factors are still strong incentives for commercial biogas plants to operate at high ammonia, resulting in demands for solutions and strategies to handle the associated problems.

Suggested physical and chemical solutions to handle the complications associated with nitrogen-rich material include dilution of substrate, air-stripping, ammonia recovery through integration of a microbial desalination cell and inclusion of material with ion exchange capacity or carbon fibre [3,4,8,9]. Furthermore, the importance of microbial adaptation to high ammonia levels has long been emphasised in the literature [4], indicating the necessity for allowing the microbial community to acclimatise to the prevailing conditions for successful operation. Recent achievements in analyses of pathways for methanisation of acetate, combined with determination of microbial community structure, provide strong indications of a significant contribution of syntrophic acetate oxidation (SAO) to methane formation in high-ammonia processes [2,10–16]. Consequently, operating parameters enhancing the activity and/or growth of key microbial constituents could potentially result in significantly improved process stability and biogas yield. Hence, this review sought to correlate current insights into microbial structures and dynamics, growth conditions of the microorganisms involved and the influence of operating parameters in SAO-mediated processes.

2. Ammonia inhibition

The dominant influence on ammonium-nitrogen concentration in digester sludge is the nitrogen content of the substrate. Organic waste streams originating from animal breeding (slaughterhouse waste, dairy wastewater stream, animal manure, aquaculture sludge) and ethanol fermentation (distiller's waste) are examples of ammonia- and protein-rich substrates commonly used for current biogas production [3–5,17,18]. The nitrogen level in certain food industry and household wastes can also be enough to perturb digester operation [19]. In addition, the level of ammonium-nitrogen is dependent on the degree of decomposition of the process, i.e. the proportion of the organic material converted to methane. A smaller