Failure Monitoring of Full Scale and Laboratory Scale Anaerobic Digesters and Evaluation of Recovery Options

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ABSTRACT

Laboratory scale experiments and measurements on full scale, overloaded, anaerobic digesters showed that large levels of volatile fatty acids can accumulate leading to digester acidification, although the hydrogen partial pressure was relatively low (<120 ppm). However, the exact hydrogen measurements showed a significant difference between failing and healthy digester sludge: the hydrogen partial pressure in healthy digesters was between 10 and 40 ppm, whereas hydrogen partial pressures of 60 to 120 ppm indicated digester failure. In the full scale digesters the raised hydrogen level did not allow propionate degradation resulting in propionate buildup to more than 60 mM over a period of 40 days. Propionate degradation was never observed as long as the hydrogen level was higher than 50 ppm. On the other hand, propionate accumulation was triggered by small increases in hydrogen partial pressures from 20 to 70 ppm. The findings show that the measurement of fluctuations in trace concentration of hydrogen but not the accumulation of large hydrogen concentrations (> 1,000 ppm) is a useful tool for digester monitoring. In the laboratory, the addition of concentrates of hydrogen consuming methanogenic bacteria, or of starved anaerobic sludge (30 to 50%) from secondary digesters, resulted in recovery of the failed digester sludge.

Keywords: Hydrogen measurement, propionate, biogas, methanogenesis, free energy change, overloading

INTRODUCTION

The biological treatment of waste can be carried out aerobically or anaerobically. Usually the concentration of the degradable organics (COD or volatile solids) decides whether aerobic or anaerobic treatment is more economical. One of the major drawbacks of anaerobic waste degradation compared to aerobic treatment systems is the higher risk of process failure. The failure of anaerobic digesters becomes obvious not only from decreased methane production rates and insufficient waste treatment but also in the accumulation of malodorous volatile fatty acids (VFA) resulting in digester acidification. In extreme cases this acidification can result in breakdown of the entire methanogenic population of the digester. This can cause major environmental and economical problems.

The origin of failure can be explained in simple terms as the disturbance of the delicate balance of hydrogen production by fermenting bacteria and syntrophic OHPA (obligate hydrogen producing acetogens) and the hydrogen consumption by the methanogenic bacteria. Usually, digester failure is caused by overloading with easily fermentable material. This excessively stimulates the fermenting bacteria resulting in hydrogen accumulation. This hydrogen accumulation causes a critical change in the thermodynamic conditions for hydrogen production. Instead of converting their substrates (e.g. carbohydrates) into mainly acetate and hydrogen, the fermenting bacteria now produce more reduced acids like propionate and butyrate. In addition, the conversion of these VFAs is inhibited by the increased hydrogen partial pressure. Thus more and more VFAs accumulate and eventually result in digester acidification. This in turn kills the methanogenic bacteria.

Since the partial pressure of molecular hydrogen appears to control which endproducts are produced by the fermenting bacteria, the hydrogen partial pressure has been measured as a performance indicator for anaerobic digesters (Archer et al. 1986, Harper and Pohland 1986, Mosey and Fernandes 1989, Whitmore and Lloyd 1986). However, recent evidence showed that hydrogen accumulation to high levels is not a suitable parameter for performance monitoring (Kidby and Nedwell 1991). In this paper we differentiate between using high levels (> 1 000 ppm) and low levels (20 to 200 ppm) of hydrogen partial pressures as potential process performance indicators.

RESULTS AND DISCUSSION

Two levels of hydrogen accumulation. In order to develop recovery options for failing anaerobic digesters, the response of healthy digester sludge to overloading was studied in the laboratory. As expected, the additon of excessive amounts of glucose or cellulose powder resulted in VFA (volatile fatty acids) accumulation and digester failure. Depending on the severity of the failure the sludge could spontaneously recover or lose the methanogenic potential. In terms of hydrogen accumulation two levels of failure severity were observed:

1. Upon shockloading with 80 mM glucose (Figure 1) the hydrogen partial pressure in the culture vessels rapidly increased from 25 to more than 50 000 ppm and acetate, propionate and butyrate accumulated rapidly to about 30 mM. Although the hydrogen level decreased within 10 days to about 120 ppm, none of the VFAs was degraded and methane production had ceased. Thus the drop in hydrogen concentration was not due to methanogenic bacteria but probably to homoacetogenic or homopropionigenic bacteria which cannot reduce the hydrogen levels as low as methanogens (Cord-Ruwisch et al. 1988).

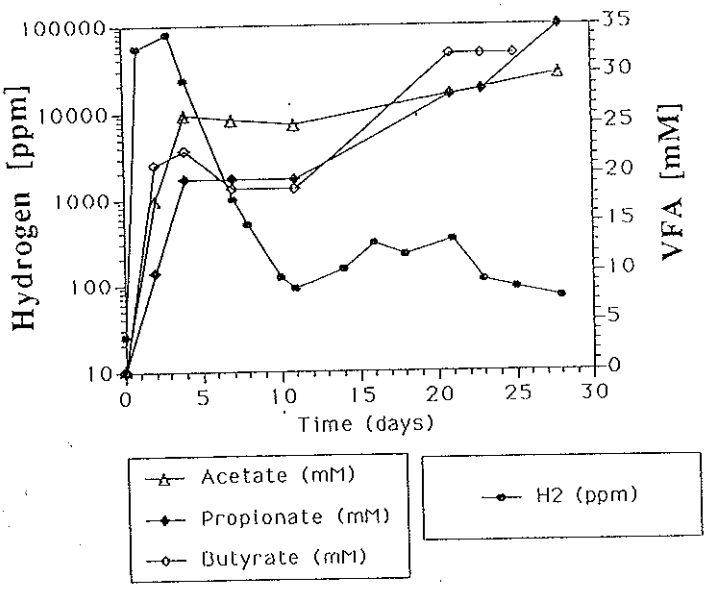

Figure 1. Effect of glucose shockload (80mM) on accumulation of volatile fatty acids and hydrogen in a healthy digester sludge, starved for 2 weeks prior to the experiment. In this experiment biogas production ceased totally after day 5.

2. Upon shock loading with 20 g/l cellulose (Figure 2) the hydrogen partial pressure only rose from 25 to 60 ppm. During this time mainly propionate accumulated. Acetate accumulated temporarily and was then converted into methane gas. Propionate degradation was only observed when the hydrogen level had lowered beyond 40 ppm. In this experiment the biogas production was only hampered but not totally stopped.The effect observed from cellulose addition was most likely due to cellulose hydrolysis being rate limiting for fermentation resulting in limited supply of sugar to the hydrogen

producing fermenting bacteria. A similar response was found when glucose was added continuously, rather than as a batch (data not shown).

These two examples were reproducible and demonstrated that digesters may accumulate VFA even though the hydrogen concentration stays relatively low (here < 100 ppm).

A failure case of a full scale (2,400m^3) reactor corresponded closely to the laboratory experiment with cellulose overloading (Figure 3). Although the hydrogen partial pressure was between 60 and 120 ppm (not shown). Propionate, but not butyrate accumulated and acetate accumulated only temporarily. The specific accumulation of propionate at these low levels of hydrogen partial pressure may be explained on thermodynamic grounds (not shown).

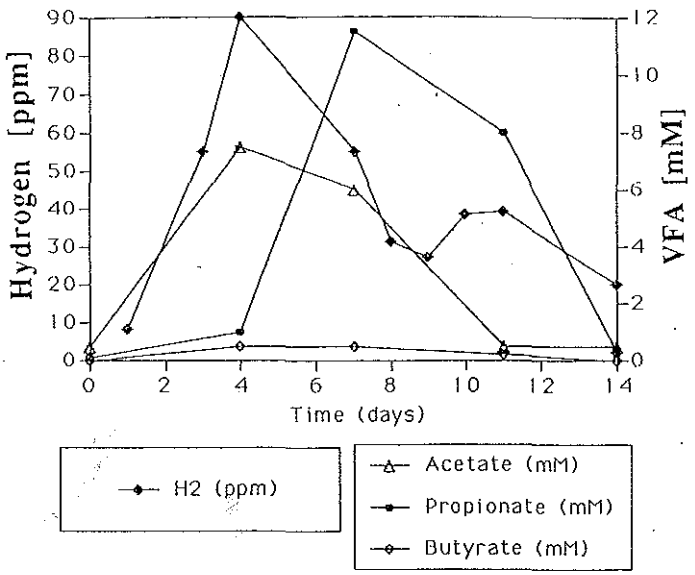

Figure 2. Effect of cellulose shock load on volatile fatty acid (VFA) and hydrogen accumulation in healthy digester sludge, starved for 2 weeks prior to the experiment.

Our results clearly demonstrate that small changes in hydrogen partial pressure correspond to propionate accumulation and degradation, respectively. If used as a failure warning indicator, or as parameter for recovery monitoring, hydrogen levels between 20 and 100 ppm need to be monitored. This requires specific detection techniques such as the mercury oxide - mercury vapour reduction technique as used in this study.

Evaluation of recovery possibilities. If the overloading situations described were in fact due to an imbalance between hydrogen production and consumption activities, then the addition of hydrogen consuming methanogenic bacteria to the failed digester sludge should stimulate digester recovery. Additon of a methanogenic enrichment culture on hydrogen to a continuously fed, slightly overloaded reactor caused complete recovery and disappearance of VFA, while control cultures did not recover.

The preparation of methanogenic bacteria in amounts sufficient to help recovering full size digesters is unlikely to be economical. Therefore starved digester sludge, low in substrate but high in viable methanogenic bacteria has been evaluated as a potential stimulant for recovery of full scale digesters (Figure 4). Strikingly, being unproductive as separated sludges (one due to extensive overloading (see Figure 3), the other due to starvation), mixtures of the two sludges started to produce gas. The level of hydrogen dropped from 70 ppm to about 30 ppm allowing propionate degradtion. However, the addition of 30 to 60 % of starved sludge was required to stimulate gas production and degradation of the propionate accumulated. The addition of less than 20 % of starved sludge was insufficient to trigger methanogenesis.

More control over the bacterial development in anaerobic digesters could reduce the risk of failures and contribute to optimizing the loading rates. Therefore the measurement of traces of hydrogen in the gas appears to be an essential tool for digester performance monitoring.

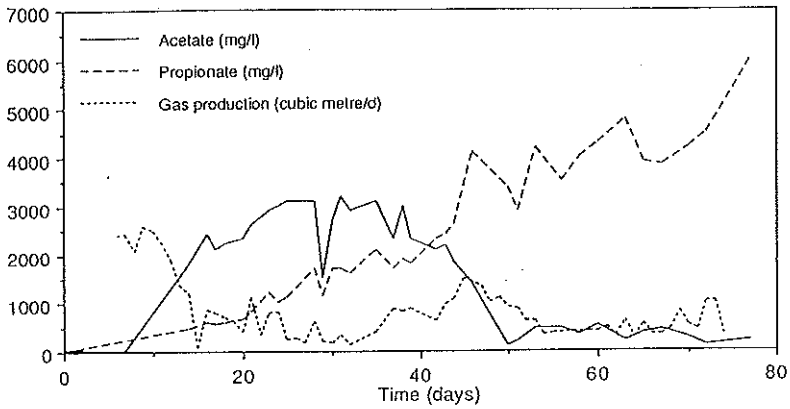

Figure 3. Time course of performance of full scale anaerobic digester (2 400 m^3) after failure occurring between day 7 and day 10. Before the failure event gas production usually was about 2,400 m^3/d).

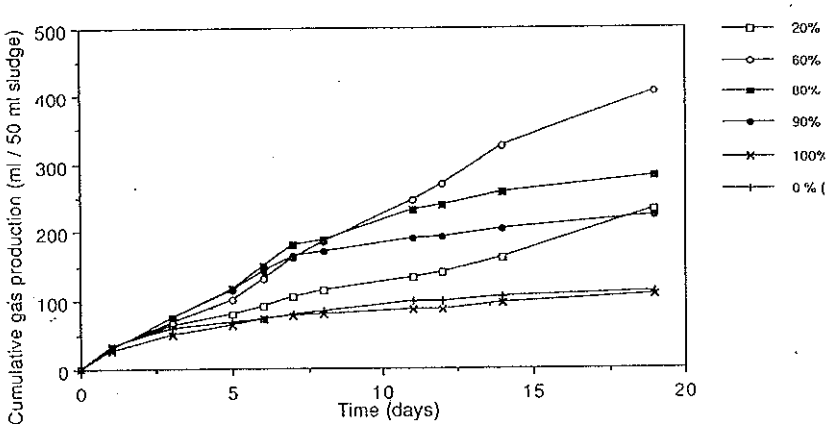

Figure 4. Biogas production of overloaded sludge (refer to figure 3) from a full scale anaerobic digester (0%), of a starved healthy sludge from a secondary digester (100 %) and of various mixtures of both sludges. Values show % of healthy sludge present in mixture.

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