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Why does mono-digestion of grass silage fail in long term operation?

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ABSTRACT

This paper presents modelling based on 340 days of operation of a small pilot-scale, 2-stage completely-mixed digester, loaded gradually up to an organic loading rate of 2.5 kg m^{-3} d^{-1}. The reactor suffered mechanical failure in the agitation system due to high solids content in the digester. This was preceded by a 20% fall in methane production (from 455 to 363 L CH_4 kg^{-1} VS added) when the loading rate was increased from 2 to 2.5 kg VS m^{-3} d^{-1}. The system was modelled using the ADM1 model which could not correctly simulate total VFA and pH in the digester system. Lactic acid is a significant element of grass silage (73% of total acids). This paper modified ADM1 through assessment of lactic acid; the results allowed close fit to experimental data. The simulation suggested that inhibition of acetogenesis initiated failure, leading to accumulation of lactic acid, reduction of acetic acid (substrate for aceticlastic methanogens), a drop in pH, less methane production, less destruction of solids, increased dry solids content and eventually failure of the mechanical agitator.

1. Introduction

There is little argument against the fact that fossil energy resources are finite, that renewable sustainable energy is required, and that there is no readily available, commercially mature, single substitute for fossil fuel. Renewable energy solutions, in particular bioenergy systems, are geographic specific. In temperate oceanic climates (such as North Western Europe) biomethane derived from grass has: a better energy balance than first generation indigenous liquid biofuels [1]; effects significant greenhouse gas savings [2]; and abundant grassland allows for significant bioresource [3]. Optimisation of the grass biomethane system requires high organic loading rates (OLRs) in the grass digesters. As OLR increases the possibility of digester failure also increases. Failure mechanisms particular to grass digestion were reported by Thamsiriroj and Murphy [4]. These include the tendency of grass to float at the liquor surface and blockages of pipes and pumps due to the fibrous nature of grass. Long term mono-digestion of grass may also result in biological failure due to the paucity of essential trace nutrients such as cobalt and selenium. The literature includes basic experimental research on the effect of addition of trace elements for mono-digestion of energy crops either to maintain biogas yields in long term operation [5,6], or to stabilise biological conditions when loaded aggressively [7–9].

Managing digester operation, while maintaining the highest possible organic loading rate (OLR), is a significant design challenge. Mathematical modelling helps to predict the most suitable OLR while minimising the possibility of failure. The ADM1 model developed by Batstone et al. [10] has been a common platform used in modelling of anaerobic digestion. The model includes conversion steps such as, disintegration, hydrolysis, acidogenesis, acetogenesis, and methanogenesis. It conserves the mass of input substrates and outputs in solid, liquid and gaseous form. It does not however include for pathways involving lactic acid formation and consumption. Lactic acid is a major component of grass silage, the accumulation of which is a key indicator of impending failure. Thus the objectives of this paper are to:

1. Modify ADM1 to allow its use for grass digestion.
2. Develop a model that readily explains 340 days of operation of a grass digestion system up to and including failure of the system.
3. Isolate the cause of failure in mono-digestion of grass silage.
4. Suggest remedial action that may have prevented failure.

2. Materials and methods

2.1. Experimental digester operation

The grass used throughout this experimentation period was harvested at the same time from the same field by the Irish Agricultural Institute (*Teagasc*). The perennial ryegrass was baled in plastic bags yielding dry solids (DS) and volatile solids (VS) content

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Table 1
Characteristics of grass silage used in modelling (adapted from 4 and 11).

pH	4.3
Protein (% DS)	9.5
Lactic acid (% DS)	4.3
Lactic acid (% total acids)	73
VFA (% DS)	1.6
Soluble sugars (% DS)	5
Oil (%DS)	3.3
C (% DS)	43.035
H (% DS)	5.82
N (% DS)	1.61
Dry solids (% total)	30.66
Volatile solids (% total)	92.46
COD equivalent (gCOD g^{-1} VS)	1.40

of ca. 31% and 92% respectively (Table 1). The system (Fig. 1a) was a small pilot-scale, 2-stage completely mixed digester operated at mesophilic temperature (37 °C). It consisted of two fermenting vessels each with a capacity for 312 L of liquor and 160 L of gas headspace [4,11]. Grass silage was fed daily to vessel 1, while the same volume of liquor was removed from vessel 2 as digestate. The liquor level in each vessel was kept equal by transferring liquor from vessel 1 to 2 through a straight pipe connection at a low level. The system also allowed for recirculation of liquor from vessel 2 to 1 to mix with input grass silage in order to keep overall solids content of the input feed below 10%. Recirculation also controls hydraulic retention time (HRT).

For example (with reference to Table 2) feeding the digester (624 L volume of two vessels) with an OLR of 1 kg VS m^{-3} d^{-1} requires 2.2 kg of grass silage (30.66% DS, 92.46% VS). To maintain the HRT at 60 days requires 10.4 kg d^{-1} of total feed input (1 L volume approximately equal to 1 kg mass). Therefore, the total feed input consists of 2.2 kg d^{-1} of grass silage and 8.2 kg d^{-1} of recirculated liquor. If the dry solids content of the recirculated liquor is ca. 3%, the overall dry solids content of the total feed input is calculated as 8.85% (less than 10%). Quantities of recirculated liquor were recorded daily. HRT calculated purely on input feedstock would be higher; in this case if we assume the silage has a density of about 400 kg m^{-3} the HRT would be of the order of 113 days. In this paper HRT will be based on that calculated including for recirculation (60 days rather than 113 days). OLR is a better indicator of reactor loading than HRT.

Fig. 1a. Picture of the digester system.

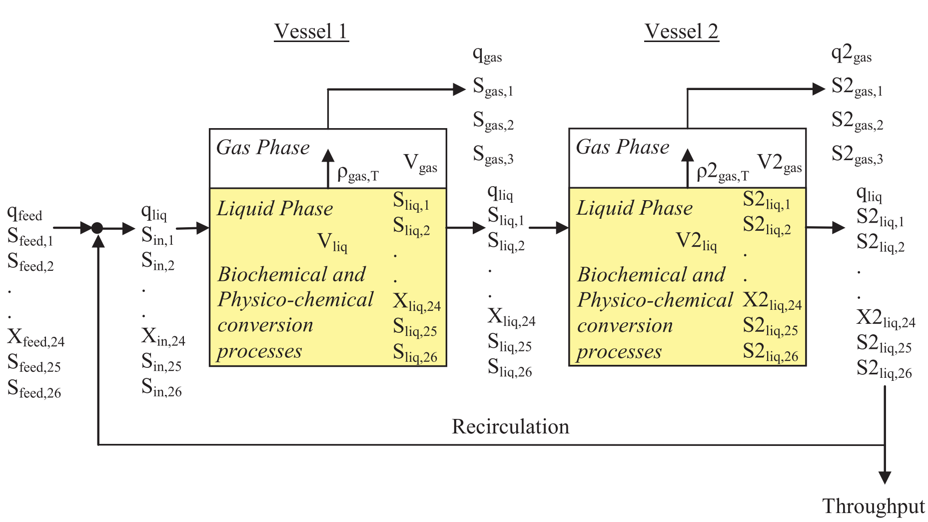

Fig. 1b. ADM1 schematic of digester model.