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Overcoming the challenges of full scale anaerobic co-digestion of casein whey

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ABSTRACT

Co-digestion of high energy wastes such as casein whey is a cost effective option for boosting biogas production from municipal anaerobic sludge digesters. This paper addresses three challenges to enable full scale application: (i) seasonality of casein whey production, (ii) slow start-up time and (iii) the large amount of manure used as a digestion aid. It is shown that casein whey, with manure as a digestion aid, can boost biogas production by 78% compared to digesting primary sludge alone. Seasonality of whey production can be overcome via ambient storage. While storage results in slightly lower specific biogas yield, it allows year round utilisation of casein whey. It was found that the digesters could be started at a primary sludge: whey: cow manure ratio of 100:50:10 for fresh whey and 100:70:10 for stored whey. These loadings of whey are much higher than previously reported for cheese whey which greatly reduces the time to reach full capacity. The volume of cow manure required to maintain a stable reactor was found to be as low as 1% of the amount of primary sludge which brings the cow manure requirements to a more viable level for full scale applications.

1. Introduction

In recent years there has been a growing interest in renewable energy production via anaerobic digestion. For example, in Germany the number of biogas plants increased by almost 20% each year from 2001 to reach 6000 by the end of 2010 [4]. Feedstocks typically used to produce this biogas include animal manure, sewage sludge, food waste, crop residuals and purpose grown energy crops [31]. However, without financial incentives it is generally not economically viable to construct new anaerobic digestion facilities [32] particularly if purpose grown crops are used rather than waste products.

Many municipal sludge digesters around the world operate at conservative organic loadings and could potentially be supplemented with additional wastes in order to boost biogas production to create sustainable energy. As opposed to construction of digesters purpose built for bioenergy generation, co-digesting additional wastes with sewage sludge avoids the initial capital costs associated with establishing new anaerobic digester facilities and thus has very favourable economics.

In order to significantly increase biogas production, the co-substrates added to the municipal digesters need to contain a high level of energy and be readily biodegradable. An opportunity to co-digest wastes for additional energy production exists in the dairy processing industry where large amounts of whey is produced. Whey is a high energy substrate which has the potential to yield large quantities of methane as it is largely made up of lactose which is readily biodegradable. The two main types of whey produced in the dairy industry are cheese whey, which is produced by adding bacterial starter cultures to the milk, and casein whey (also called acid whey) which is produced by adding acid (e.g. sulfuric acid) to the milk. While there are several uses for whey, approximately half of the total whey produced globally is currently disposed of to waste [11]. This is particularly the case during peak months of milk production where excess whey is either irrigated onto land or disposed of via a wastewater treatment plant [20]. Casein whey in particular presents a significant problem and is more likely to be disposed of to waste than cheese whey due to its low food value [21] and the presence of high levels of lactic acid which can taint the taste of food products [29].

Globally it is estimated that approximately 85 million tonnes of whey is produced every year [25]. The amount which is specifically casein whey is not reported. However, it can be estimated at approximately 11 million tonnes given that just 3 kg of casein is

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yielded per 100 kg of skim milk [27] and that annual global casein production is 330,000 tonnes [30]. Due to the high organic strength and difficulty in otherwise disposing of casein whey, converting this waste into useful energy via anaerobic digestion is a particularly attractive opportunity. However, to date anaerobic digestion of whey is very poorly researched particularly with regards to casein whey.

While many components present in casein whey are similar to cheese whey, one of the most significant differences is the pH. The pH of casein whey is typically 4.4 which is much lower than cheese whey which typically has a pH of 6.1 [23]. This lower pH could potentially make anaerobic digestion of casein whey more difficult. In countries like New Zealand the majority of casein is produced using sulfuric acid [27] which consequently produces whey high in sulfate. This could also be potentially challenging for an anaerobic digester as the sulfate can be converted to sulfide by sulfate reducing bacteria [6]. This then leads to two problems within the reactor. First, the sulfate reducing bacteria compete with the methanogens for organic substrates [17] which reduces the biogas production within the reactor and secondly sulfide could reach inhibiting levels for various groups of bacteria within the digester [14].

While there are a number of published studies on the anaerobic digestion of cheese whey (eg Refs. [2,10,13,18,33]) and the co-digestion of cheese whey with other substrates including sewage sludge [5], dairy manure [9,16] and poultry manure [11], this contrasts against only one published paper on the anaerobic digestion of casein whey. Clark [7] digested casein whey in an upflow anaerobic sludge blanket reactor and encountered significant problems.

Whey has a low alkalinity which can result in digester failure due to a lack of buffering capacity [12]. In order to achieve a stable reactor pH when digesting whey some researchers have used chemical addition [13]. However, as an alternative to chemical addition a growing amount of research has shown that digestion aids such as cow manure can be added to stabilise anaerobic digesters [3,26]. These digestion aids should ideally be locally available, low cost and required in relatively small amounts compared to the main substrates for biogas production. Shilton et al. [26] found that small amounts of cow manure used as a digestion aid when co-digesting primary sludge and cheese whey resulted in a more stable digester and was actually more effective than adding chemical alkalinity. It is currently not known whether the same will be possible with casein whey.

Once co-digestion of primary sludge, casein whey and cow manure has been evaluated there are still several barriers to full scale implementation. Each of these barriers are identified and explained below.

(a) *Seasonality*

Whey production is typically seasonal resulting in large quantities of whey being produced for a short period of time. In order to maximise the use of this substrate it needs to be stored and fed into the digester when feedstock is not directly available from the dairy factory in the off season. Powell et al. [24] found cheese whey could be stored at ambient temperature with only a small reduction in its organic strength. It is likely that lactic acid bacteria degraded the cheese whey during storage as these bacteria would have been added to the milk as an inoculum during the cheese making process. Casein whey is however produced by adding acid to lower the pH without the use of lactic acid bacteria. In this case it is not known if the same lactic acid fermentation will occur during casein whey storage and what effect this will have on biogas production.

(b) *Slow start-up*

Whey is known to be difficult to anaerobically digest [19] and its addition can quickly lead to digester failure [22]. While it has been shown that adding cheese whey and cow manure to a primary sludge digester can boost biogas production and result in stable operation [26] the reactors in the study all started at conservative initial levels of cheese whey in order to allow the reactor to slowly acclimatise to the new feedstock. Over 300 days were taken to reach maximum biogas production. For full scale application acclimation needs to be much faster due to seasonality but it requires a careful balance between getting the anaerobic digester to full production while taking enough time to maintain stability. It is currently unknown how quickly this can be achieved.

(c) *Cow manure requirements*

A number of studies have used cow manure to stabilise anaerobic digestion of whey (for example [3,8,15,26]). Bertin et al. [3]; have suggested that a whey to cow manure ratio of 1:1 should be used. However, at full scale this would require massive amounts of cow manure which could lead to substantial transport costs associated with its supply. Shilton et al. [26] showed when co-digesting primary sludge and cheese whey, cow manure could be added at just one fifth the amount of primary sludge to produce a stable reactor. However this ratio remains yet to be optimised with much lower ratios potentially possible.

This paper investigates the feasibility of co-digesting casein whey in a municipal primary sludge digester and then each of the barriers identified above are explored.

2. Methods

2.1. Feedstocks

The primary sludge was obtained from the Palmerston North City Council, New Zealand and the casein whey was collected from Fonterra dairy factory in Longburn, Manawatu, New Zealand. The cow manure was regularly collected from the Massey University No. 1 Dairy farm from the cowshed yards. The composition of each of the feedstocks is given in Table 1.

A portion of the casein whey was placed in a 20 L vessel which was stored at 15 °C. The purpose of this was to mimic storing whey in ambient conditions in a temperate climate. The whey was regularly monitored during the storage period. This was then used as a feedstock in various reactors where it is referred to as 'stored whey'. The whey was stored for a period of at least four months before it was used as feedstock for the reactors.

2.2. Reactor set-up

The digesters consisted of 2 L Erlenmeyer flasks which were operated as semi-continuous reactors to mimic the operating procedure of the primary sludge digester at the Palmerston North

Table 1
Average composition of feedstocks.

Component	Primary sludge	Casein whey	Cow manure
Total COD (mg/L)	27,900	72,900	118,900
Soluble COD (mg/L)	7800	72,800	29,000
Total VFA (mg/L)	650	550	450
Acetate (mg/L)	270	440	90
Alkalinity (mg/L)	540	460	4500
pH	5.60	4.54	6.84