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A case study for biogas generation from covered anaerobic ponds treating abattoir wastewater: Investigation of pond performance and potential biogas production

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HIGHLIGHTS

- We report on the performance of a novel covered anaerobic pond system.
- Potential biogas production was estimated using BioWin modelling software.
- Ponds maintained stable operation; however, accumulation of crust was an issue.
- Modelling indicated that biogas yield can be influenced by decomposition efficiency.
- Configuration and operation of ponds can also impact potential biogas production.

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ABSTRACT

Covered anaerobic ponds offer significant advantages to the red meat processing industry by capturing methane rich gas as a fuel source for bioenergy while reducing greenhouse gas emissions (GHG). This paper presents the results of a novel-designed anaerobic pond system at an Australian abattoir in relation to pond performance and potential biogas production. Key findings in assessing the effectiveness of the system revealed that the covered ponds are capable of efficient wastewater decomposition and biogas production. The primary issue with the covered ponds at the abattoir was the build-up of fat/crust that prevented the accurate measurement of biogas and effective use of the cover. In the absence of field biogas data the novel application of the computer modelling software BioWin® was carried out to simulate chemical oxygen demand (COD) removal rates and subsequent biogas yield. The unique parameter used to fit field data was the fraction of the inlet COD due to a superficial crust which did not follow anaerobic digestion. Field data effluent COD removal rates were matched to simulated rates predicted by BioWin when measured influent COD was reduced to 30%. Biogas modelling results suggest significant variation in the economic benefit of biogas energy, with the quantity of biogas potentially varying tenfold (from 328 m^3/d to 3284 m^3/d) depending on site factors such as pond efficiency, pond configuration and operational practices.

1. Introduction

Anaerobic waste treatment ponds are widely adopted in the meat industry as the first stage of secondary treatment of high-strength abattoir wastewater and are an efficient means whereby the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are reduced by around 90% during ideal conditions [1]. They are the preferred option for treating agricultural wastewater in Australia due to their relatively low initial cost, negligible operating costs and simplicity of operation [2]. However, they have a couple of issues including odour emissions and the generation of methane, a powerful greenhouse gas (GHG). The Australian red meat processing industry has a high exposure to carbon pricing due to wastewater methane emissions and its use of coal for steam generation [3]. Consequently, the industry is beginning to install covered anaerobic pond technology [4]. Despite higher initial infrastructure costs when compared to uncovered anaerobic ponds, covered anaerobic ponds offer significant advantages such as odour control, intensification of the decomposition process and BOD removal, an increase in feed rate and the potential for capturing methane-rich gas as a fuel source for bioenergy and the reduction in GHGs [4–6]. Energy obtained from the biogas can be used in an internal combustion engine coupled to an electric generator to

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Nomenclature

ARE	absolute relative error
BOD	biochemical oxygen demand
COD	chemical oxygen demand
DAF	dissolved air flotation
EC	electrical conductivity
FOG	fats, oils and greases
GHG	greenhouse gas
HDPE	high density polyethylene
HRT	hydraulic retention times
ML	mega litre
OLR	organic loading rates
ORP	oxidation-reduction potential
SRT	solid retention time
TA	total alkalinity
tHSCW	tonnes of hot standard carcass weight
TKN	total Kjeldahl nitrogen
TSS	total suspended solids
VFA	volatile fatty acid

produce electrical power, or simply be used in boilers. Also, the liquid fraction from this process can be used as liquid fertilizer [7].

Knowledge regarding the design of these ponds and the quantity and quality of biogas captured remains largely undetermined. Modelling has previously been used to predict biogas production after calibration. In a study by Martinez et al. [8] modelling was used to simulate slaughterhouse effluent waste degradation and methane generation after it was demonstrated that the model showed an accurate reproduction of the behaviour of an anaerobic digester. Modelling the biogas production process can be used as an indication of the process performance. This may identify actions for better control of the process operation that positively impact the biogas yield [9].

This paper firstly provides contextual background information and proceeds to report on the performance of a novel designed covered anaerobic pond system installed at an Australian abattoir in relation to wastewater treatment and biogas production. The study also reports on the novel application of BioWin® computer modelling software to simulate biogas yield in a field-based situation and provides an economic assessment of biogas recovery and use based on these modelled results.

2. Overview of operation and performance of anaerobic ponds treating abattoir effluent

Red meat processing produces wastewater with a high pollutant load consisting of paunch, manure, fats, oils and greases (FOGs), and uncollected blood. These components contribute to a high-strength waste which must be treated to reduce the BOD, COD, FOGs and total suspended solids (TSS) [10]. FOGs are large contributors to BOD and COD and while FOGs have the potential to produce large quantities of methane [11], their recalcitrant nature generally results in a number of problems [12]. Some of the problems include: clogging of pipes; foul odour generation; adhesion to the bacterial cell surface and reducing their ability to treat wastewater; and flotation of sludge and loss of active sludge [13,14]. FOGs also tend to accumulate on the surface of ponds to form a recalcitrant scum layer or 'crust' [15,16] which can hamper attempts to accurately measure biogas. However, primary treatment systems such as dissolved air flotation (DAF) units with chemical treatment are capable of reducing FOGs by up to 89–98% [5].

Anaerobic digestion is said to be working optimally when the acid formation phase (hydrolysis and acidogenesis) and the methane production phase (acetogenesis and methanogenesis) occur simultaneously in dynamic equilibrium [17]. Stability of the anaerobic process is difficult to maintain because a balance favourable to several microbial populations is necessary and the comparatively stable nature of the acid formers and the fastidious nature of the methane formers creates a biosystem that is prone to upset as a result of shock loads or temperature fluctuations [18]. Therefore, for the design of an anaerobic pond to perform optimally, it must be based on the limiting characteristics of these microorganisms. Pond oxidation–reduction potential (ORP), temperature, NH_3 concentration, pH, volatile fatty acid (VFA) to total alkalinity (TA) ratios (VFA/TA) are all parameters which are indicative of pond performance and should be monitored [1]. However, criteria for anaerobic pond design are poorly defined and no widely accepted overall design equation exists [19]. Previously, pond construction criteria for the red meat processing industry has been derived from other industries, and this has resulted in pond designs which have not necessarily been suitable. Design is typically based on organic loading rates (OLR) and hydraulic retention times (HRT) from pilot plants and observations of existing pond systems [19]. Generally, the desired goal is to achieve significant reductions in wastewater organic load with the least HRT possible [15]. Anaerobic ponds are designed based on an OLR to promote sedimentation of wastewater solids and efficient anaerobic digestion to biogas. Compared with anaerobic digesters, anaerobic ponds are designed for relatively low OLRs [20]. Overloading of ponds has the undesirable effect of accumulating inhibitory substances which inhibit biogas production and reduce biogas yield. As a general rule, an increase in organic loading must be balanced by an increase in HRT to achieve equivalent treatment efficiency of the wastewater [21].

There is currently a lack of knowledge within the Australian red meat processing industry regarding the design and operation of anaerobic ponds and upgrading these to covered anaerobic ponds to minimise GHG from wastewater treatment operations. Also, there is a clear lack of published literature which details biogas production using this technology with the recoverable quantity and quality of biogas remaining largely unclear. In the absence of meaningful field gas measurements it is difficult to assess the feasibility of using covered anaerobic ponds to generate bioenergy. Computer modelling software has become widely adopted in wastewater engineering over the past two decades. Although evolved principally as a research tool they are now used more for design and optimisation of wastewater treatment plants [22]. BioWin is a Windows based computer simulation model which is increasingly used to predict anaerobic digestion processes and subsequent biogas yield [23]. It is used primarily to simulate wastewater treatment for domestic sewage and there has been no application to meat processing waste to date. However, anaerobic ponds that treat abattoir effluent utilise the same complex microbiological processes responsible for the anaerobic decomposition of domestic wastewater. Thus there is great scope to apply the tool in this situation given the uncertainty surrounding accurate biogas measurements due to crust and solid accumulation.

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