2006

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Publication Details

Tie, L. & Sivakumar, M. (2006). Dairy shed wastewater treatment by anaerobic digestion technology. Environment Working Together - A Multi-Disciplinary Approach: 10th Annual Environment Postgraduate Conference (pp. 282-287). Cairns, QLD AUSTRALIA: James Cook University.

DAIRY SHED WASTEWATER TREATMENT BY ANAEROBIC DIGESTION TECHNOLOGY

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ABSTRACT: Continued growth and consolidation of the livestock industry such as dairy industry has generated large-quantities and high-strength manure, which has long been identified as a major contributor to diffuse source pollution in Australia. However, conventional dairy shed wastewater treatment practices in Australia such as two pond systems still do not provide sufficient treatment. In addition, relevant laws and regulations in terms of nutrient management plans and manure solids disposal require new waste management approaches.

Anaerobic digestion (AD) is an efficient, small footprint, cost effective and sustainable technology that should be applied in Australian dairy farms, and has the potential not only to minimise the environmental impacts but also to maximise resource recovery especially generation of useful renewable bio-fuel (methane) including wastewater reuse. In order to be able to design and operate efficiently anaerobic digestion systems, appropriate mathematical models need to be developed to observe and analyse the anaerobic process dynamics and accordingly optimize anaerobic digestion applications before investment of construction and installation.

The present paper critically reviews AD technology in the context of dairy shed wastes and AD modelling. The necessity of AD application on Australian dairy farming is discussed, based on conventional dairy waste management practices and relevant laws and regulations. Also the advantages of AD technology are illustrated by comparing traditional and integrated dairy waste management practices. The unique characteristics of Australian dairy shed wastes, the knowledge gap and future trends of AD technology have been identified. As a result, it is known that AD technology should be extended to Australian dairy farming.

KEY WORDS: anaerobic digestion, AD technology, dairy shed wastewater, dairy manure

PREFERRED PRESENTATION FORMAT: Platform

1. INTRODUCTION

1.1 Current situation of Australian dairy farming

Currently, dairy farming is Australia's third largest rural industry with a farm gate production value of over $3.2 billion in 2004/2005. The total number of registered dairy farms has decreased from 22,000 in 1980 to just over 9,250 in 2005. On the contrary, the average herd size per farm has increased from 85 cows in 1980 to an estimated 217 in 2004/05 (Dairy Australia, 2005). As a result, the increasingly intensive dairy farming practices is generating greater volumes of more concentrated waste in a dairy shed (Wrigley, 1994; Hubble and Phillips, 1999; Longhurst et al., 2000). Also the large quantity of high-strength wastewater from dairy farming operations has long been identified as a major contributor to diffuse source pollution due to organics, pathogens, nutrients and gas emissions, leading to surface and groundwater contamination and air pollution (ANZECC and ARMCANZ, 2000; NSW EPA, 2003).

1.2. Conventional practice of Australian dairy farming

Conventional dairy shed wastewater treatment practices such as land systems and pond systems in Australia still do not provide sufficient treatment for the effluents to be safely disposed into receiving lands and waterways (Hopkins, 1999). Land systems is the most common forms (commonly referred to as sump-pump systems), which convey drained effluent wastewater from a sump to suitable application areas immediately following wash down via pipes or channels. Lack of control over the quality of applied effluent (particularly untreated wastewater) results in unpredictable release of available nutrients as runoff (Crocos, 2000). Pond systems are currently the Best Management Practice (BMP) for storage and treatment purposes. It can be categorised into a single deep-water (anaerobic) pond, two-pond system including a primary (anaerobic) pond and a secondary facultative (aerobic) pond, or a series of ponds including maturation pond(s) for effluent polishing. However, some operational aspects of pond systems limit their effectiveness including sludge accumulation in primary anaerobic ponds, inefficient pretreatment (screening) facilities, poor understanding of nutrient processing and effluent nutrient content (fertilizer value), seepage losses and potential for groundwater contamination, or the long-term viability of recycling secondary pond effluent as yard flush water (Fyfe and Hagare, 2004; Scott McDonald, 2006). Therefore, conventional best management practice facilities can’t provide ideal solution to dairy shed waste treatment. Also they occupy large land area and no recovery of energy is possible.

1.3. Relevant laws and regulations of Australian dairy farming

Relevant laws and regulations require new waste management approaches. For meeting the requirements of state environmental protection legislations shown in Table 1, numerous state government departments around Australia have already set up some guidelines or codes of practice to minimise the impacts of dairy effluent pollution. For example, as part of the national water quality management strategy, ANZECC (ANZECC and ARMCANZ, 1999) have drawn Effluent Management Guidelines for dairy processing and for dairy sheds wastes. The state governments department have also drafted corresponding Codes of Practice for Milking Shed Effluent (Government of South Australia, 2003) or dairy industry waste reduction plan (New South Wales Government, 1998) to prevent wastewater discharging into water. At the same time, they also have encouraged farmers to improve their waste management practices by providing technical and financial assistance in implementing sound waste management practices such as new techniques of treatment, re-use and disposal (Monks and Wrigley, 1993).

Table 1: The summary of state environmental protection legislations

Title of Act	Year	State	Reference
Clean Waters Regulations	1972	NSW	(NSW EPA, 1972)
Protection of the Environment Operations Amendment Act	2005	NSW	(NSW EPA, 2005)
Environment Protection Act	1970	Victoria	(Victorian EPA, 1970)
Environment Protection (Amendment) Act	2006	Victoria	(Victorian EPA, 2006)
Tasmanian Dairy Industry Act	1994	Tasmania	(Tasmanian Dairy Industry Authority, 1994)
South Australian Water Resources Act	1997	South Australia	(SA EPA, 1997)
Western Australian Environmental Protection Act	1986	Western Australia	(WA EPA, 1986)

The current management practices and laws and regulations require that state government authorities (e.g. NSW DEC) and livestock producers seek more efficient and cost-effective waste treatment technology. Among the various methods of waste treatment, anaerobic digestion (AD) is one of the more promising sustainable technologies to treat dairy shed waste that has the potential not only to minimise the environmental impacts but also to maximise resource recovery especially generation of useful renewable bio-fuel (methane) including wastewater reuse.

2. ANAEROBIC DIGESTION (AD) TECHNOLOGY

2.1 The definition of anaerobic digestion

Anaerobic Digestion is a biochemical degradation process by which complex organic matter (animal manure or biomass) is decomposed by microbial population in the absence of oxygen into biogas and other by-products (Lusk, 1998). It includes four reaction stages to convert insoluble particulate organic material to two final chemical products (70% CH_4 and 30% CO_2). The stages are: hydrolysis (by hydrolytic bacteria), acidogenesis (by acidogenic bacteria), acetogenesis (by acetogenic hydrogenating and dehydrogenating bacteria) and methanogenesis (by hydrogenotrophic and acetoclastic bacteria) (Evans, 2001).

2.2 The benefits of anaerobic digestion technology

When proven, anaerobic digestion will provide three significant benefits:

Firstly, it can benefit the environment and community by reducing land and water pollution, recycling nutrients and achieving significant removal of odorous compounds and pathogens (Wilkie, 2000; Metcalf and Eddy, 2003).

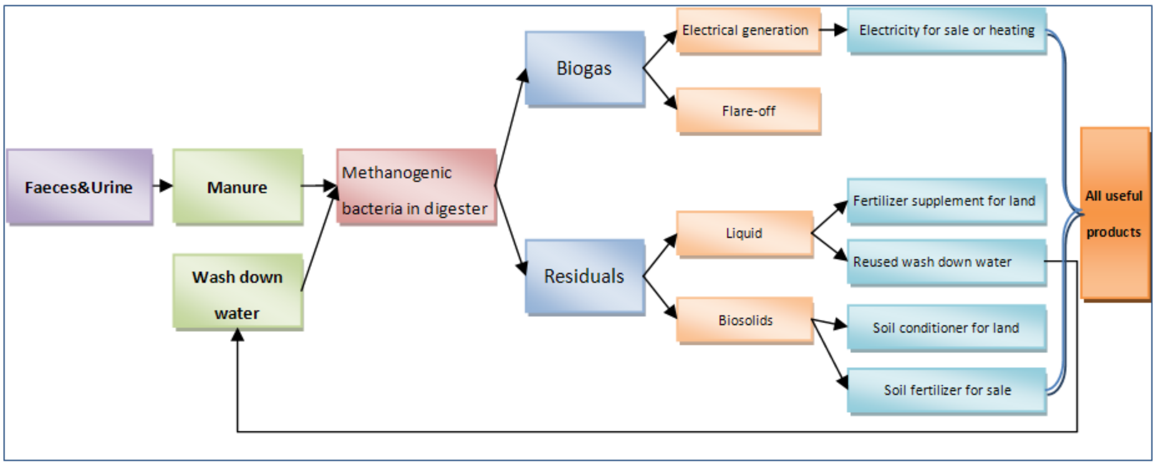

Figure 1: Anaerobic digestion process of dairy manure

Secondly, it can bring economic benefits for industry and business by saving costs in improving farm waste management and by converting a variety of end-products into potentially saleable products for increasing income and savings. All products of anaerobic digestion (AD) process are highly valuable as illustrated in Figure 1. Biogas is a renewable and relatively clean fuel, which contains methane used to power machinery and generate electricity and heat (Kramer, 2004). Liquid effluent has high contents of soluble and suspended nutrients making it a valuable fertiliser supplement for land application, or can be reused as wash down cleaning water in order to reduce the daily operational cost (Anonymous, 2000). Solid By-product (SBP), which is the sludge or settlement recovered by a dehydration process, could be used as a nutrient-rich soil conditioner for land application and off-site sale (Steinsberger and Shih, 1983).

Thirdly, the corresponding social benefit of anaerobic digestion is creating or maintaining job opportunities due to potential stimulation of new industries (Midwest Rural Energy Council, 2004). Consequently, anaerobic digestion technology is considered as an alternative approach, which could not only provide an improved form of waste treatment but also convert a waste problem into useful and valuable by-products.

2.3 Integrated AD systems into dairy waste management practices

Conventional wastewater management practice in agriculture generally relies on a combination of different types of treatment ponds designed to lower the pollution potential of effluent before it is discharged into a natural water course. In Australian dairy farms, a two pond system consisting of an anaerobic and an aerobic pond is most commonly used (Wrigley, 1994; Scott McDonald, 2006).

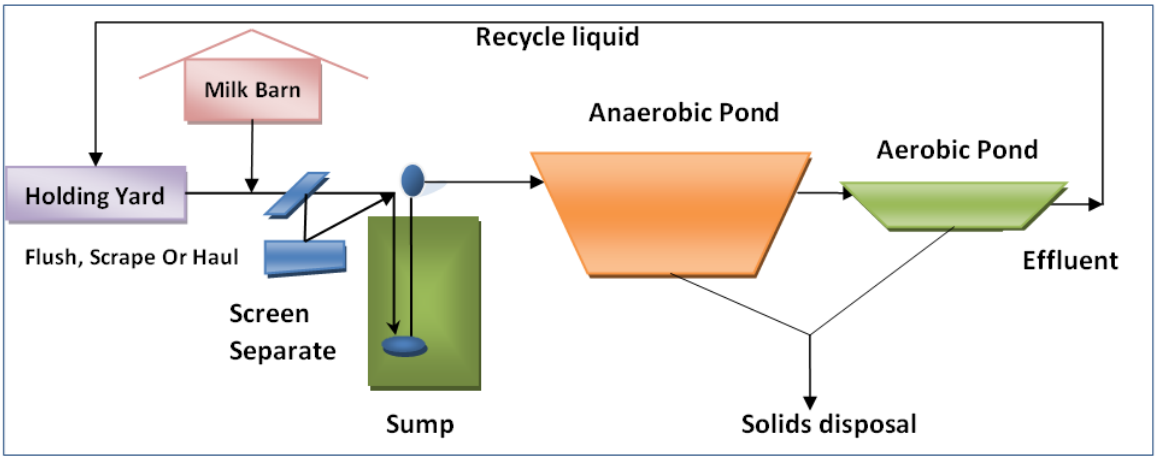

Figure 2: Dual-pond system with effluent recycled for flood washing

Figure 2 presents the detailed waste handling system of typical Australian dairy farming. It can be seen that dairy shed wastes is firstly collected by hydraulic-flushed system, then through collection channel into solid separation system. It includes solid traps for capturing large amount of sludge, and concrete sumps which act as a combined screen and settling basin to effectively remove the major portion of solids and organic fibers. The screened and settled dairy shed wastewater goes into a two-pond system for treatment and stabilization, which consists of primary anaerobic pond and secondary facultative pond, followed by a recycle pump system that recycles the treated wastewater for flood washing. However, the dual-pond system has been proven problematic with frequent occurrence of overflows during wet weather events and groundwater pollution, and hence there is a need for a better technology such as anaerobic digestion.

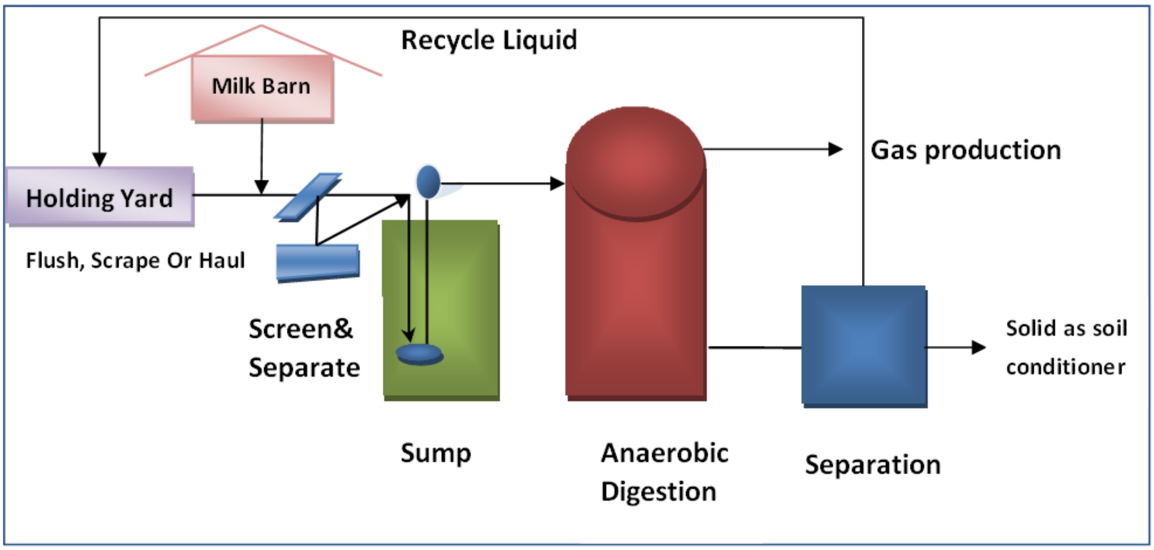

Figure 3: Integration of Anaerobic Digestion in Dairy Waste Management Practice

For harnessing all benefits of anaerobic digestion technology, modification of the existing dairy management system becomes necessary, which could potentially incorporate the recovery of biogas into conventional systems to afford further integration. Figure 3 shows how anaerobic digester can be incorporated in an existing dairy waste-processing stream. It can represent either two-pond system or only the primary anaerobic pond to recovery the valuable bioenergy and by-product. System selection is mainly depending on dairy waste characteristics, wastes loading rate, anaerobic digester treatment efficiency and initial investment cost. If low or moderate concentrations of sand are present, the raw waste stream may be discharged to an anaerobic digester, bypassing the existing screen and solid trap. If high concentrations of solids are present, the existing solid separators may remain in place in order to reduce the corresponding operational problems. Under such conditions, a reduced quantity of organics will be converted to gas.

3. THE KNOWLEDGE GAP OF ANAEROBIC DIGESTION TECHNOLOGY

Harnessing of biogas using AD process as the natural energy source has already been successfully initiated in livestock industries, including dairy, in Europe and the US (Dagnall, 1995; Morse et al., 1996; CADDET Renewable Energy, 1997; Guillermo and Matti, 1999; Seadi, 2000). In Australia, anaerobic digestion technology for electricity generation has been implemented only in Berrybank Piggery Farm, Victoria (Australian Centre for Cleaner Production, 1998; Quinney, 2004; Department of Agriculture Fisheries and Forestry, 2006).

Table 2: The comparison of dairy shed wastewater characteristics

	Dairy shed wastewater				
	Australia			*NZ*	*USA*
Parameter	(Wrigley, 1994)	(Fyfe, 2004)	(Tie et al., 2004)	(Longhurst et al., 2000)	(Sweeten and Wolfe, 1994)
BOD_5, mg/L	3200	927	858		
COD, mg/L		4191	2318		6720
Total Solids (TS), mg/L		4044	6156		5804.7
Volatile Solids (VS), mg/L			3433		3778.3
Suspended Solids (SS), mg/L	2400	2009			3063
Total Phosphorus (TP), mg/L	25.9	43.3		69	62
Total Nitrogen (TN),mg/L	187	266		342	304.01
Ammonia (NH3-N),mg/L	83.6	72		48	280.1
Total Potassium, mg/L	200			370	383.9
pH	8	8.3	7.6		7.55
Salt (as EC), dS/m	1.12	2.18	3.47		4
Chloride, mg/L	180				193
Sodium, mg/L	119			54	155
Magnesium, mg/L	27			39	93
Sodium, Adsorption Ratio	4.3	1.1			2.1

Although widely-applied overseas experience to treat agricultural waste has proven useful, it lacks validity in Australia as it has not been used in dairy farming. The different feed pattern and waste collection system in Australian dairy farms lead to special characteristics of dairy shed wastewater (Wrigley, 1994). Table 2 gives the comparison of Australian dairy shed wastewater with USA and NZ wastewater. In the United States (US), many dairy farms are lot-fed and house the herd permanently, which produce a continuous waste stream and thus greater volumes of more concentrated wastewater. However, most dairy farms in Australia are pasture-based, hence deposited manure only accumulates during milking sessions, which generate more diluted wastewater (typically less than 1% TS) amounting to approximately 8-10% of the total manure production of the herd, and results in low gas production potential (Hubble and Phillips, 1999; Sukias et al., 2001). The similar situation exists in New Zealand (Longhurst et al., 2000). The dilution problem can be overcome by either separating solids from the wash down water for subsequent digestion in a conventional reactor, or by using a unit specially designed to handle low solids waste such as an anaerobic filter or lagoon. Therefore, further research into AD feasibility to Australian dairy shed waste streams is considered a worthwhile pursuit.

Desktop laboratory studies undertaken at the University of Wollongong (Fyfe, 1999; Sivakumar et al., 2003; Fyfe, 2004; Sivakumar et al., 2004) have indicated strong potential for applying anaerobic digestion and biogas harvesting technology to dairy shed waste streams. In addition, a preliminary laboratory study was undertaken by the authors using the anaerobic digestion of screened dairy waste (Tie et al., 2004). The results were comparable with similar studies undertaken overseas (Lo et al., 1984; Liao and Lo, 1987; Dugba and Zhang, 1999; Wilkie, 2003), and also proved that anaerobic digestion can be successfully applied to hydraulically flushed dairy shed waste for the generation of biogas on typical Australian dairy farms.

4. CONCLUSION

This study analysed in detail the dairy shed wastewater treatment by anaerobic digestion technology in the context of Australian dairy farming conditions. To meet the changing’s laws and regulations as well as working towards sustainable management of dairy shed wastewater, the application of AD technology will be very important. The nature of AD process and its corresponding benefits have also shown that this alternative technology can not only minimise the environmental pollution, but also maximise bioenergy recovery and by-product reuse. Future research direction should be directed towards identifying the most efficient and cost-effective reactor configurations and waste handling systems.

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