Australian Government

Rural Industries Research and Development Corporation

RURAL INDUSTRIES

Research & Development Corporation

Options for Biogas Cleaning and Use On-farm

DECEMBER 2012

RIRDC Publication No. 12/056

Australian Government

Rural Industries Research and Development Corporation

Options for Biogas Cleaning and Use On-farm

by Alan Skerman, Gary Collman, Jae Ho Sohn and Lyle Pott

December 2012

RIRDC Publication No. 12/056
RIRDC Project No. PRJ-004547

ISBN 978-1-74254-399-4
ISSN 1440-6845

Options for Biogas Cleaning and Use On-farm
Publication No. 12/056
Project No. PRJ-004547

Researcher Contact Details

Alan Skerman
Department of Agriculture, Fisheries and Forestry
PO Box 102
203 Tor Street
TOOWOOMBA QLD 4350

Email: Alan.Skerman@daff.qld.gov.au

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600

PO Box 4776
KINGSTON ACT 2604

Phone: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au.
Web: http://www.rirdc.gov.au

Electronically published by RIRDC in December 2012
Print-on-demand by Union Offset Printing, Canberra at www.rirdc.gov.au
or phone 1300 634 313

Foreword

Methane is the dominant greenhouse gas emission from Australian agriculture and has been identified as a priority area for emission reductions within the livestock sector. The potential for capture and use of methane is greatest in the intensive livestock industries, where manure management is estimated to contribute three percent of the emissions from Australian agriculture.

The project documented in this report was funded by the Australian Methane to Markets in Agriculture (AM2MA) program, which is a collaborative venture between government and industry, receiving funding from the Climate Change Research, Natural Heritage Trust and National Landcare programs administered by Department of Agriculture Fisheries and Forestry (DAFF). The AM2MA program also receives industry funding and support from the Rural Industries Research and Development Corporation, Dairy Australia, Australian Pork, Meat and Livestock Australia, the Australian Lot Feeders' Association, and the Australian Chicken Meat Federation.

This project involved developing and installing a robust, low-cost scrubber to condition the biogas collected by a partial floating cover installed on the primary anaerobic effluent pond at the QNPH piggery near Grantham in south-east Queensland. This cover was installed under an earlier AM2MA project (Project No. PRJ-003003) described by Skerman *et al* (2011). The main objective of the scrubber installation was to reduce the hydrogen sulphide concentration so that the biogas quality was suitable for long-term on-farm use.

The other major objective was to install and monitor the operation of a biogas-fired water heater used to heat water circulated through pads installed in the piggery farrowing pens. The biogas water heater has been installed alongside an existing LPG fired water heater and it is anticipated that the available biogas will be used to replace approximately half of the current LPG consumption, resulting in significant energy savings.

The outcomes of this project will benefit intensive livestock producers by reducing the risk involved in establishing biogas treatment and use systems. This will encourage producers to implement similar systems for the purpose of reducing their energy consumption and GHG emissions. The technologies developed in this project will also assist pig producers with the adoption of the recently launched CFI methodology.

The objectives of the AM2MA program are:

- development and adaptation of methane capture and use technology for application in the Australian intensive livestock industries
- reduction of the uncertainty, risk and cost of installing methane capture and use systems
- effective communication of project outcomes
- facilitation of commercialisation of on-farm systems for methane capture and use technology.

This report is an addition to RIRDC's diverse range of over 2000 research publications and it forms part of our AM2MA R&D program, which aims to develop/adapt methane capture and use technology for application in Australian intensive animal industries.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

QNPH Grantham piggery owners, Messrs Jeremy Whitby and Graham Bourke.

Piggery manager, Mr Darren Keep and piggery employees.

Australian Methane to Markets in Agriculture (AM2MA) program manager, Mr Griff Rose.

Program funding provided through the Australian Methane to Markets in Agriculture (AM2MA) program by Climate Change Research, Natural Heritage Trust and National Landcare programs, administered by Department of Agriculture Fisheries and Forestry (DAFF).

Abbreviations

AM2MA	Australian Methane to Markets in Agriculture program
APL	Australian Pork Limited
CHP	Combined heat and power (biogas use system)
CH_4	Methane
CO_2	Carbon dioxide
DAFF (Qld)	Department of Agriculture, Fisheries and Forestry (Queensland)
DCCEE	Department of Climate Change and Energy Efficiency
GWP	Global warming potential
H_2S	Hydrogen sulphide
H_2SO_4	Sulphuric acid
HRT	Hydraulic retention time
LPG	Liquid petroleum gas
MCFC	Molten Carbonate Fuel Cells
PEM	Proton Exchange Membrane Fuel Cells
PAFC	Phosphoric Acid Fuel Cells
RIRDC	Rural Industries Research and Development Corporation
SOFC	Solid oxide fuel cell
SO_2	Sulphur dioxide
SPU	Standard pig unit
TS	Total solids
VS	Volatile solids

Contents

Tables

Figures

Executive Summary

What the report is about

This project has investigated technologies for conditioning biogas for on-farm use, primarily focusing on the removal of hydrogen sulphide. While several existing technologies have been successfully developed and used for removing H_2S in large-scale industrial applications, this project has attempted to identify and demonstrate robust, cost-effective options, suitable for implementation on farms of various sizes, with minimal labour input and limited specialised expertise.

In addition to investigating biogas cleaning (conditioning), this project has also involved installing a water heating unit burning biogas to heat water that is circulated through floor heating pads installed in the farrowing sheds at the QNPH Grantham piggery. This biogas fired heating system has the potential to significantly reduce on-farm energy costs by replacing a significant proportion of the Liquid Petroleum Gas (LPG) previously used for farrowing shed heating.

Who is the report targeted at?

The information provided in this report will assist producers, industry bodies, researchers, industry service providers, contractors, government policy makers and regulators who have an interest in the planning, design, installation and operation of biogas capture, treatment and reuse systems at Australian intensive livestock production facilities.

Where are the relevant industries located in Australia?

The outcomes of this research are directly applicable to the Australian pork industry and could be adapted to other intensive livestock industries, particularly the dairy industry. The pork and dairy industries operate in all Australian states. There has been considerable interest in adopting biogas collection, treatment and use systems within the Australian pork industry in recent years. At the present time, several major Australian pig producers are in the process of investigating, planning or constructing on-farm biogas systems. The recent introduction of the Carbon Farming Initiative (CFI) ‘Methodology for the destruction of methane generated from manure in piggeries’ (DCCEE, 2011) has resulted in increased producer and industry interest in adopting on-farm biogas technology.

Background

One of the major obstacles hindering the uptake of technologies for productively using the significant energy value of biogas produced by intensive livestock industries is the quality of the raw biogas collected by covered ponds or anaerobic digesters. Various degrees of biogas treatment are necessary, depending on the desired gas utilisation process. Hydrogen sulphide (H_2S) is typically the most problematic contaminant because it is toxic and corrosive to most equipment, while the sulphur dioxide (SO_2) emitted when H_2S is burnt, is harmful to the environment. Consequently, removal of H_2S is recommended to protect biogas use equipment, increase safety, and enable possible utilisation of more efficient technologies.

This project involved developing, installing and monitoring the operation of a biogas scrubber and water heating system which utilise biogas collected from the partially covered anaerobic pond located at the Queensland Natural Pork Holdings (QNPH) Grantham piggery. The partial floating cover was retrofitted to an existing anaerobic effluent pond at this piggery under an earlier AM2MA project (Project No. PRJ-003003). Details of the piggery operation, cover design, installation and performance data are provided in the Final Report prepared for this project by Skerman *et al* (2011).

Aims/objectives

The objectives of this project were to identify and demonstrate robust, low-cost designs of equipment to condition biogas for on-farm use – particularly to remove hydrogen sulphide; and to demonstrate the use of biogas for shed heating.

This trial was initially intended to focus on the above objectives, with the possibility of negotiating an extension to assess the suitability of commercially available technologies for other methods of on-farm utilisation of biogas, including: internal combustion engines, micro-turbines, and absorption chillers/gas fridges. Due to time and budgetary constraints, this third objective was not addressed in this project.

Methods used

This project was implemented as follows:

- A literature search was carried out to investigate suitable scrubber design options.
- Preliminary designs were prepared for a water scrubber and an iron sponge scrubber which were considered to be the most promising options.
- Further investigation suggested that an iron sponge scrubber would be the most practical, cost-effective option for installation at the Grantham piggery.
- An iron sponge scrubber was fabricated and installed using a second-hand stainless steel cheese making vessel as a base.
- A relatively small quantity of the commercial scrubbing medium, SULFA-BIND® was purchased for comparison with a number of alternative, lower cost scrubbing media options.
- It is proposed to monitor the scrubber performance over time, and to compare the performance of the various scrubbing media.
- A commercial hot water system originally designed to burn natural gas was purchased, installed and converted to run on biogas, to offset the LPG used for heating farrowing sheds by circulating hot water through floor heating pads.
- It is proposed to monitor the hot water system operation over an extended period to evaluate its performance under various seasonal conditions.
- The biogas quality will be monitored closely to evaluate its variability under a range of seasonal conditions, to assess its suitability for a range of uses, and to evaluate the performance of the biogas scrubber.

Results/key findings

The biogas scrubber and water heating system have been installed and are now operational at the Grantham piggery. Due to delays in the upgrading of the biogas system at the piggery, limited monitoring data is currently available.

Untreated biogas composition data recorded at the piggery, suggests average methane, carbon dioxide and hydrogen sulphide concentrations of 69%, 30% and 1637 ppm, respectively. The average methane concentration is consistent with the data reported by Skerman *et al* (2011). Due to its corrosive nature, the average hydrogen sulphide concentration suggests that use of the untreated biogas would have adverse effects on the life expectancy of appliances such as hot water boilers, internal combustion engines, Stirling engines and fuel cells. This highlights the need for a robust, relatively simple, cost effective scrubber to remove a significant proportion of the hydrogen sulphide from the biogas.

It is anticipated that a dry scrubbing method using iron sponge media (or a more recently developed commercial product) to adsorb H_2S from the biogas stream will prove to be the most suitable technology for adoption in small to medium sized intensive livestock production facilities. Commercial scrubbing media and lower cost alternatives will be further evaluated over a minimum 12 month period to determine the most cost effective approach.

Implications for relevant stakeholders

Federal Government estimates at the time of the recent CFI methodology launch indicated that there are approximately 690 piggeries in Australia which could potentially implement biogas collection and flaring/use systems. Without the implementation of abatement measures, piggery emissions are expected to be 1.3 Mt CO_2-e by 2020. It is estimated that an emission abatement of around 50% of this figure could be achieved through the installation of biogas collection and flaring/use systems, in accordance with the CFI methodology.

In systems where the biogas is used as an energy source for shed heating and/or electrical power generation, further reductions in GHG emissions will result, along with savings in energy costs.

This level of uptake by industry will not be achieved unless producers have confidence in the available technology and likely economic returns. The outcomes of this project will contribute to a reduction in risk associated with the adoption of the CFI methodology, particularly for smaller scale producers who may not be able to afford to employ specialist consultants and contractors to carry out the required design and installation.

In addition to GHG abatement, if Australian intensive livestock producers are going to benefit from the significant energy resources and resulting cost savings available from the collection of biogas, they will need practical guidance on the selection and use of technologies for treating the biogas to an appropriate standard to enable effective use of the biogas. These technologies must be robust, cost effective, and relatively simple to operate with minimal labour, while requiring minimal input of specialised chemicals.

The technologies developed and evaluated in this project were selected to meet these criteria. Following the conclusion of the proposed performance monitoring period, it is anticipated that the resulting findings will provide valuable guidance for intensive livestock producers contemplating the installation of biogas capture, treatment and use systems.

Recommendations

Delays in the installation of the biogas scrubber and shed heating system at the Grantham piggery severely curtailed opportunities to monitor the performance of the system.

To maximise the benefits resulting from the significant investment already made in establishing the facilities at the Grantham piggery, it is recommended that the project contract be extended (at no additional cost) until June 2013, to enable the performance of the biogas scrubber and water heating system to be monitored for an additional 12 month period. The resulting data will assist in resolving outstanding technical and regulatory issues while providing producers with clear evidence of the potential benefits and costs associated with the installation and operation of biogas collection and use systems.

An addendum to this Final Report should be prepared following the conclusion of the extended monitoring period.

Introduction

Background

Methane is the dominant greenhouse gas emission from Australian agriculture and has been identified as a priority area for emission reductions within the livestock sector. The potential for capture and use of methane is greatest in the intensive livestock industries, where manure management is estimated to contribute three percent of the emissions from Australian agriculture.

Recent life cycle assessment studies (Wiedemann *et al*, 2010) suggested that the main sources of global warming potential (GWP) in producing pork result from the production of feed upstream of the piggery and the management of piggery effluent. In conventional housing piggeries, this was particularly noticeable, with 66% of the overall GWP coming from the ponds at the piggery. However, this emission source can be controlled through various technologies such as pond covering and flaring to burn methane, which may reduce overall emissions by up to 50% across the supply chain.

The recent launch of the Carbon Farming Initiative (CFI) *Methodology for the destruction of methane generated from manure in piggeries* (DCCEE, 2011) provides pig producers with a new source of revenue for undertaking projects that capture and burn methane emitted from anaerobic ponds. Under this methodology, the methane can be either flared or utilised for productive heating or power generation purposes, effectively converting the methane to carbon dioxide which has a significantly lower GWP. This will enable producers to generate carbon credits which can be sold in emerging carbon markets.

One of the major obstacles affecting the uptake of technologies for productively using the significant energy value of biogas is the quality of the raw biogas collected by covered ponds or anaerobic digesters. Biogas consists mainly of methane (CH_4) and carbon dioxide (CO_2), with smaller amounts of water vapour and trace amounts of hydrogen sulphide (H_2S), and other impurities. McKinsey Zicari (2003) states that various degrees of biogas processing are necessary, depending on the desired gas utilisation process. Hydrogen sulphide is typically the most problematic contaminant because it is toxic and corrosive to most equipment. Additionally, combustion of H_2S leads to sulphur dioxide (SO_2) emissions, which have harmful environmental impacts (acid rain and particulate pollution). Consequently, removal of H_2S, as soon as possible (after the gas is emitted from the source), is recommended to protect downstream equipment, increase safety, and enable possible utilisation of more efficient technologies.

This project has investigated technologies for conditioning biogas for on-farm use, primarily focusing on the removal of hydrogen sulphide. While several existing technologies have been successfully developed and used for removing H_2S in large-scale industrial applications, this project has attempted to identify and demonstrate robust, low-cost designs, suitable for implementation on farms, ranging in size from relatively small to large, with minimal labour input and limited specialised expertise.

This project, which was funded by the Australian Methane to Markets in Agriculture (AM2MA) program, was carried out at the Queensland Natural Pork Holdings (QNPH) Grantham piggery. A partial floating cover was retrofitted to an existing anaerobic effluent pond at this piggery under an earlier AM2MA project (Project No. PRJ-003003 Biogas production by covered lagoons – QNPH piggery, Grantham Queensland). Details of the piggery operation, cover design, installation and performance data are provided in the Final Report prepared for this project by Skerman *et al* (2011).

In addition to investigating biogas cleaning (conditioning), this project has also involved installing a water heating unit that burns biogas to heat water that is circulated through the piggery farrowing sheds to keep the piglets warm. This biogas fired heating system has been integrated into an existing Liquid Petroleum Gas (LPG) fired water heating system. The new system has the potential to significantly reduce on-farm energy costs by using the biogas to supplement/replace LPG consumption.

Piggery details

The Queensland Natural Pork Holdings (QNPH) ‘Palahra’ piggery is situated approximately 1.2 km south-west of the town of Grantham in the Lockyer Valley, south-east Queensland, as shown in Figure 1. The town of Grantham is approximately 100 km west of Brisbane.

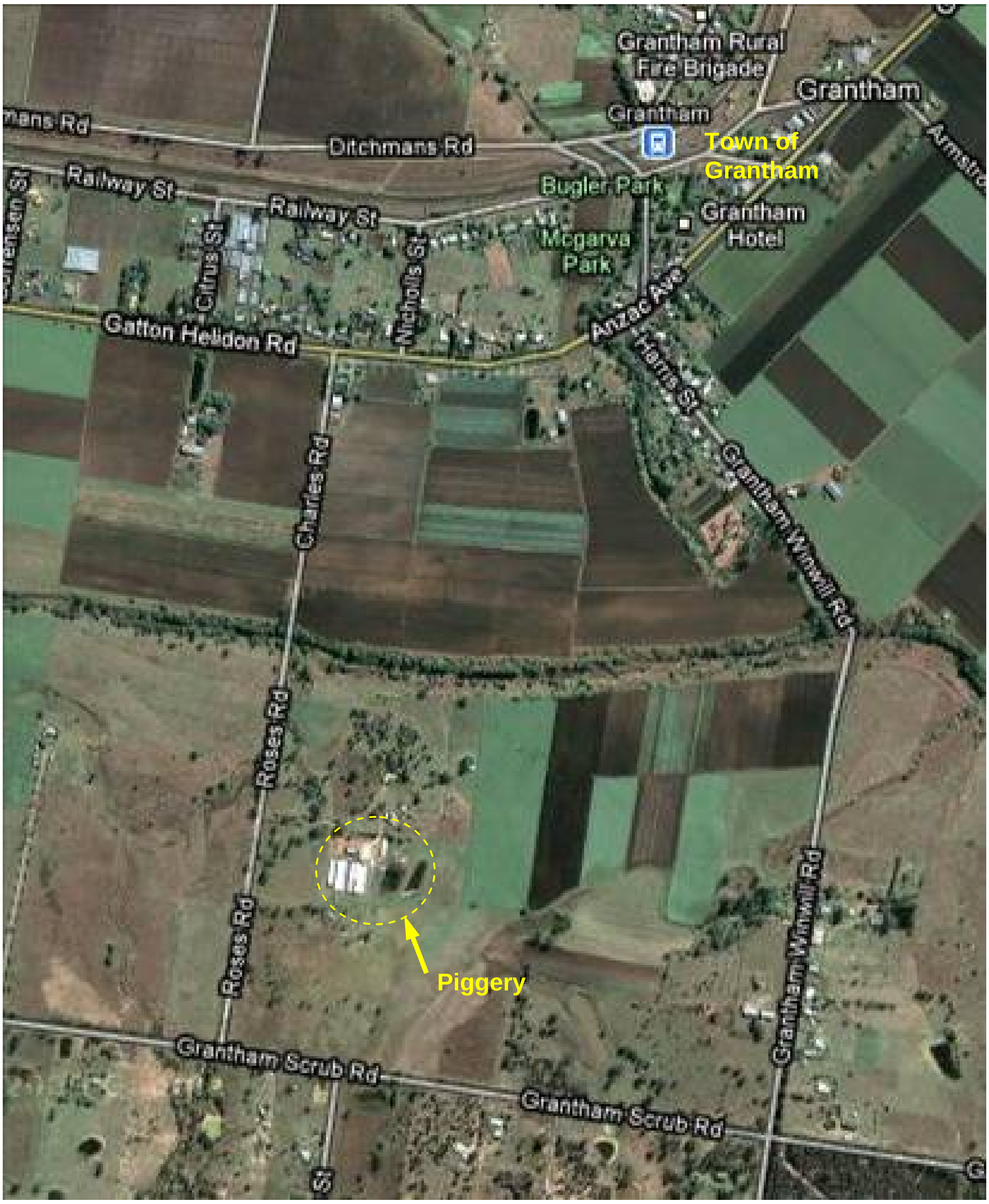

Figure 1. QNPH ‘Palahra’ piggery location, near the town of Grantham, south-east Queensland.

The piggery operates as a specialised breeder unit, housing 700 sows. Weaned piglets are transported off-site, to contract grower units, at 3 to 4 weeks of age. The resulting 1600 pigs (1400 standard pig units - SPU) at the site are housed in two dry (gestating) sow sheds and two farrowing sheds with partially slatted floors. The pig manure and hosing water is collected in static pits, located under the shed floors. Effluent is released weekly from the static pits and is conveyed into a primary anaerobic treatment pond, via a 300 mm diameter gravity pipeline. The primary pond overflows by a gravity pipeline into a secondary pond.

The primary and secondary ponds have capacities of 1.7 and 1.5 ML respectively, resulting in a primary pond volatile solids (VS) loading rate of approximately 0.2 kg VS. m^{-3}. day^{-1}, with a hydraulic retention time (HRT) of approximately 130 days. An aerial photograph of the piggery is provided in Figure 2.

Figure 2. Aerial photograph of the piggery showing the locations of the partially covered primary effluent pond, biogas pipeline, water heating unit and biogas scrubber.

Biogas system details

The AM2MA Steering Committee decided to trial the use of a partial floating cover at the Grantham site as they felt that it may provide a convenient retro-fit option for installation on existing effluent ponds at intensive livestock production facilities. Furthermore, other sites included in the AM2MA program (e.g. Bear's Lagoon piggery) were already employing a full pond cover secured by trenching into the embankment. Deployment of a partial floating cover at the Grantham piggery enabled the evaluation of a potentially viable alternate option.

The AM2MA Steering Committee selected a Dunedin (New Zealand) based company, Waste Solutions, to design and install the partial floating cover and associated biogas management system at the QNPH Grantham piggery. Waste Solutions employed a subsidiary company, Total Constructions Limited (TCL) to carry out the on-site fabrication and installation of the floating cover. The floating pond cover was fabricated on-site over a period of approximately one week, prior to launching on 20 February 2009. Installation of the original biogas control and monitoring equipment was completed on 25 February 2009.

As shown in the aerial photograph (Figure 2), the floating cover is rectangular in shape, having dimensions of approximately 30 m x 25 m covering approximately half of the pond surface area. The cover was fabricated on the relatively flat, grassy area between the primary effluent pond and the piggery sheds.

Skerman *et al* (2011) reported an average biogas yield from the covered pond of 65 m^3/day, with an average methane concentration of 73%, resulting in an average methane yield of 47.5 m^3/day (32.2 kg CH_4/day). This is equivalent to an average daily methane yield per mass of VS entering the pond of 0.15 m^3 CH_4/kg VS or 0.10 kg CH_4/kg VS.

Skerman *et al* (2011) estimated that the average biogas yield could produce 1606 MJ/day of primary (heat) energy. This energy could be used to offset the LPG currently used to heat water circulated through concrete heating pads in the farrowing pens, resulting in a potential saving of $23,000 per year.

Biogas system upgrade

During the course of RIRDC Project No PRJ-003003, it was identified that certain components of the original biogas management system (flare, blower, gas meter, data logger, pressure sensor, flame arrester, programmable logic controller and associated pipeline and fittings) installed at the Grantham piggery site by Waste Solutions Ltd, did not comply with the Queensland gas safety legislation, viz. the *Petroleum and Gas (Production and Safety) Act and Regulation, 2004*. Furthermore, it appeared that the installation was not carried out in accordance with the legislation and no certificates of compliance or approval were issued.

A review of the installed system carried out by a type B gas approval authority (Hyde Combustion Pty Ltd) identified areas of non-compliance requiring rectification. A quotation was provided by an authorised type B gas installer (Williamson Brothers, Toowoomba) to upgrade the existing system to achieve compliance with the relevant legislation. Documentation was prepared to facilitate a competitive tender process to proceed. Funding for the system upgrade was included as Stage 1 of the subsequent RIRDC Project No PRJ-005672. The agreement for this project was signed on 20 August 2010.

Tenders for the Stage 1 upgrade closed in October 2010. The only offer received for the upgrade exceeded the original quotation and project budget by a factor of approximately three. Due to authorisation issues resulting from a change in business ownership, Williamson Brothers (who submitted the original quotation) did not submit an offer for this tender. Following resolution of the authorisation issues, Williamson Brothers submitted a revised offer which was subsequently accepted in March 2011. Following significant delays in the delivery of several system components from overseas, the upgraded system (Stage 1) was eventually re-installed during November 2011.

In addition to upgrading the biogas management system installed by Waste Solutions Ltd, RIRDC Project No PRJ-005672 included the installation of a pipeline to deliver biogas from the management system, located near the north-western corner of the covered pond, to the proposed water heating unit, located between sheds 2 and 3, as shown in Figure 2. This work which was designated as Stage 2, involved installing underground HDPE pipeline from the biogas management system to the eastern side of shed 4, and elevated stainless steel pipeline over the rooves of sheds 3 and 4. The Stage 2 installation was completed in March 2012, following delays in the supply of stainless steel pipe and fittings. The hot water system was installed and converted to burn biogas during April 2012. Following the installation of the electrical control system, the heating system was commissioned in April 2012.

The delays experienced in the upgrading of the biogas system (stage 1) and installing the biogas pipeline and water heater prevented the commencement of scrubber and water heating trials. Consequently, no performance data for the scrubber and water heater was available at the time that this report was written.

It is understood that RIRDC has approved the continuation of this project for a further 12 month period to enable the collection of scrubber and water heating performance data. It is anticipated that an addendum to this report will be completed following the conclusion of the extended monitoring period, in June 2013.

Objectives

The following objectives were specified in the Research Agreement:

- To identify and demonstrate robust, low-cost designs of equipment to condition biogas for on-farm use – particularly to remove hydrogen sulphide. (The literature suggests that the proposed scrubbing method should be capable of reducing the hydrogen sulphide concentration to 2 ppm. This concentration will be adopted as the scrubber performance target for this trial.)

- To demonstrate the use of biogas for shed or piglet heating.

- To assess the suitability of commercially available technologies for on-farm utilisation of biogas, including: internal combustion engines, micro-turbines, and absorption chillers/gas fridges.

This trial will initially focus on the first two objectives, with the possibility of negotiating an extension to address the third objective.

Methodology

Scrubber development

As noted previously, one of the major obstacles affecting the uptake of technologies for productively using the significant energy value of biogas is the quality of the raw biogas collected by covered ponds or anaerobic digesters. Hydrogen sulphide is typically the most problematic contaminant because, even at relatively low concentrations, it is toxic to humans and corrosive to pipelines, fittings and most equipment used to utilise the energy value of the biogas. Additionally, combustion of H_2S produces sulphur dioxide (SO_2) emissions, which have harmful environmental impacts (acid rain and particulate pollution). Consequently, removal of H_2S, as soon as possible (after the gas is emitted from the source), is recommended to protect downstream equipment, increase safety, and enable effective utilisation using a range of technologies.

This project has investigated processes for conditioning biogas for on-farm use, primarily focusing on the removal of hydrogen sulphide. While several existing technologies have been successfully developed and used for removing H_2S in large-scale industrial applications, this project has attempted to identify and demonstrate robust, low-cost designs, suitable for implementation on farms, ranging in size from relatively small to large, with minimal labour input and limited specialised expertise.

The required level of biogas treatment depends on the end use of the biogas. McKinsey Zicari (2003) provides a summary of biogas processing requirements for a range of potential biogas utilisation technologies in Table 1.

Table 1. Biogas utilisation technologies and gas processing requirements (McKinsey Zicari, 2003)

Technology	Recommended gas processing requirements
Heating (Boilers) [1]	H_2S < 1000 ppm, 0.8-2.5 kPa pressure, remove condensate (kitchen stoves: H_2S < 10 ppm)
Internal Combustion Engines [1]	H_2S < 100 ppm, 0.8-2.5 kPar pressure, remove condensate, remove siloxanes. (Otto cycle engines more susceptible to H_2S than diesel engines)
Microturbines [2]	H_2S tolerant to 70,000 ppm, > 350 BTU/scf, 520 kPa pressure, remove condensate, remove siloxanes
Fuel Cells [3]	PEM (Proton Exchange Membrane): CO < 10 ppm, remove H_2S PAFC (Phosphoric Acid Fuel Cells): H_2S < 20 ppm, CO < 10 ppm, Halogens < 4 ppm MCFC (Molten Carbonate Fuel Cells): H_2S < 10 ppm in fuel (H_2S < 0.5 ppm to stack), Halogens < 1 ppm SOFC (Solid oxide fuel cell): H_2S < 1 ppm, Halogens < 1 ppm
Stirling Engines [4]	Similar to boilers for H_2S, 1-14 kPa pressure
Natural Gas Upgrade [1, 5]	H_2S < 4 ppm, CH_4 > 95%, CO_2 < 2 % volume, H_2O < (1 x 10^{-4}) kg/MMscf, remove siloxanes and particulates, > 3000 kPa pressure

Sources:
[1] Wellinger and Linberg (2000), [2] Capstone Turbine Corp.(2002), [3] XENERGY (2002), [4] STM Power (2002), [5] Kohl and Neilsen (1997)

From Table 1, it can be seen that technologies employing external combustion such as boilers and Stirling engines have the least stringent gas processing requirements. Internal combustion engines and microturbines are the next most tolerant to contaminants, while fuel cells are generally less tolerant to contaminants due to the potential for catalytic poisoning. Upgrading to natural-gas quality usually requires expensive and complex processing and must be done when injection into a natural-gas pipeline or production of vehicle fuel is desired (McKinsey Zicari,2003).

In Australian intensive livestock industries, the utilisation technologies most likely to be adopted in the short term involve the use of boilers for heating water, internal combustion engines for electrical power generation, and combined heat and power (CHP) systems. While microturbines are another possible option, fuel cells are unlikely to be used in the short term. Upgrading for use in the natural gas grid seems to be an unlikely utilisation method at present in Australia.

Krich (2005) describes the following H_2S removal processes:

- Air injected into the digester biogas holder
- Iron chloride added to the digester influent
- Reaction with iron oxide or hydroxide (iron sponge)
- Use of activated-carbon sieve
- Water scrubbing
- Sodium hydroxide or lime scrubbing
- Biological removal on a filter bed

A literature review suggested that the biogas upgrading methods most likely to be adopted by the Australian intensive livestock industries were water scrubbing and the use of iron sponge adsorption media.

Water scrubber

The feasibility of fabricating and trialling a relatively simple, counter-current, packed tower type of water scrubber, based on the bench-scale reactor described by Tanaka (2002), was investigated. This type of scrubber did not require any chemical additives and had a relatively low labour requirement. It was intended to assess the effectiveness of different scrubbing media while varying the biogas flow through the scrubber to establish optimal contact times between the biogas and scrubbing liquid.

Water scrubbers rely on the absorption principle which involves the transfer of a substance (H_2S and CO_2) from a gaseous phase, to a liquid phase, through the phase boundary. Water scrubbers selectively remove both H_2S and CO_2 from the biogas because these gases are more soluble in water than CH_4. Water scrubbers require contact between the untreated gas moving up through the counter-current packed tower, and the water stream flowing down through the tower. The packing medium provides a large surface area for this contact, so that the H_2S and CO_2 can be absorbed into the water stream.

A preliminary scrubber design was prepared based on the gas production rates measured at the QNPH Grantham piggery under RIRDC project No PRJ-003003 (Skerman, 2011) using commercial tower packing media (No 2, Type K Tellerettes), as shown in Figure 3.. A schematic drawing of the preliminary design is provided in Figure 4.

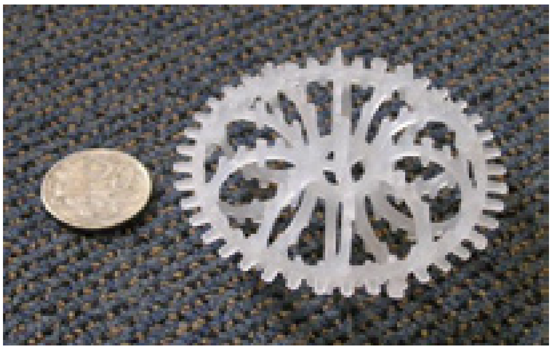

Figure 3. No 2, Type K Tellerette tower packing media for use in water scrubber.

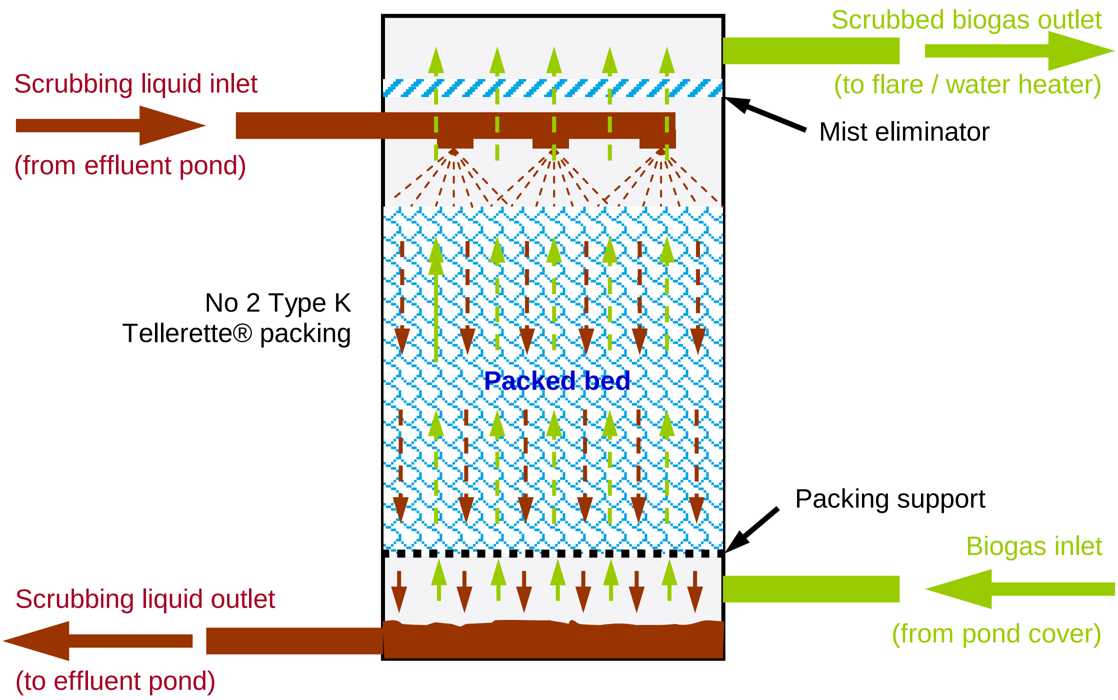

Figure 4. Possible counter-current flow, packed-bed water scrubber schematic drawing.

It was decided to defer further development of the water scrubber, in favour of an iron sponge type of dry scrubber following further examination of the literature and consideration of the issues outlined below:

It was noted that fuel gas must be odorised so that any gas leaks are readily detectable. If the scrubber removed sufficient H_2S from the biogas, it may lose its distinctive odour and be subject to additional safety measures. This appears to be highly unlikely given the extremely low odour recognition threshold of H_2S (0.0047 ppm) at which 50% of humans can detect the characteristic odour of hydrogen sulphide, normally described as resembling "a rotten egg" (Powers, 2004). This is significantly lower than the target scrubber performance objective of 2 ppm specified for this project.

This issue could be addressed by locating the scrubber as close as possible to the point of use, i.e. near the water heater, thereby minimising the risk of leakage of deodorised gas along the delivery pipeline. It was originally intended to locate the water scrubber near the biogas management system, beside the north-western corner of the partially covered primary effluent pond, and to use pond effluent as the scrubbing liquid. Because the water heater is located between sheds 2 and 3, approximately 60 m from the primary effluent pond, it would be impractical to use pond effluent as the scrubbing liquid.

Furthermore, the solids content of the primary pond effluent may result in the retention of solids in the scrubber packing medium. While this issue could be at least partially addressed by using secondary pond effluent which has a significantly lower solids concentration, the greater distance to the secondary pond and the lack of a nearby electric power source makes this option impractical.

Another issue to be considered is the disposal of the sulphur rich liquid discharged from the scrubber. It was originally intended to discharge this liquid into the primary effluent pond and to monitor the chemical composition and pH of the discharged liquid and pond effluent. It is unknown whether this liquid would have any adverse effects on the pond anaerobic decomposition process or odour emission.

The requirement to operate a pump (possibly continuously) to circulate the scrubbing liquid through the packed tower would also reduce the net energy gain from utilising the biogas.

Iron sponge scrubber

Due to the issues identified previously relating to water scrubbers, it was decided to initially trial treating the biogas using a dry scrubbing method which utilises an iron-rich media, often referred to as 'iron sponge'. It is expected that this method will be the most practical, cost-effective option for many on-farm biogas systems.

The 'iron-sponge' method for removing H_2S from industrial gases is one of the oldest methods still in practice (McKinsey Zicari, 2003). Iron oxide (Fe_2O_3) impregnated scrubbing media remove sulphur from the gas stream by forming insoluble iron sulphides (Fe_2S_3), as described in Equation 1. From this equation, it can be seen that one kg of Fe_2O_3 stochiometrically removes 0.64 kg of H_2S.

$Fe_2O_3 + 3H_2S \rightarrow Fe_2S_3 + 3H_2O$ $\Delta H = -22$ kJ/g-mol H_2S Equation 1.

The term 'iron sponge' is generally used to describe the scrubbing medium consisting of wood chips impregnated with iron oxide. More recently, proprietary iron-oxide or ferric hydroxide based media such as SulfaTreat ®, Sulfur-Rite ®, SULFA-BIND ® and Media-G2 ® have become available as improved alternatives to iron sponge (McKinsey Zicari, 2003). A limited amount of SULFA-BIND ® was purchased for trial during this research project. A manual for the use of this product is provided in the Appendix. It is also planned to assess the effectiveness of some less costly scrubbing media such as iron-oxide impregnated wood chips and possibly other iron-rich waste products during this trial.

The iron-oxide in the scrubbing medium is eventually exhausted. The bed life of the batch process is dependent upon the quantity of H_2S in the biogas stream, the amount of iron oxide in the bed, residence time, pH, moisture content, and temperature (Gas Processors Suppliers Association, 2004). When the iron oxide is consumed, the bed must be regenerated by exposure to oxygen to convert the iron sulphide back to iron oxide and elemental sulphur, as described in Equation 2.

$2Fe_2S_3 + O_2 \rightarrow Fe_2O_3 + 3S_2$ $\Delta H = -198$ kJ/g-mol H_2S Equation 2

This can be done in batch mode by removing the medium from the scrubber and exposing it to air. McKinsey Zicari (2003) suggests that the sponge can be spread out into a layer 0.15 m thick, and kept continually wetted for 10 days. Because the regeneration process described by Equation 2 is highly exothermic, it is imperative to manage the heat build-up in the sponge during regeneration to maintain activity and prevent combustion (Revell 1997). The Gas Processors Suppliers Association (2004) recommends that the entire bed should be wetted before beginning the change-out operation. Due to the build-up of elemental sulphur and loss of hydration water, iron sponge activity is reduced by one third after every regeneration. Therefore, regeneration is only practical once or twice before new iron sponge is needed. Taylor (1956) suggests that only about 85% of the theoretical removal efficiency (0.56 kg H_2S/ kg Fe_2O_3) can be achieved in this mode.

As an alternative to batch regeneration, the iron sponge medium can be continuously regenerated by introducing a small amount of oxygen into the gas stream. It is claimed that most commercial iron sponge materials can be regenerated several times before the media becomes clogged with elemental sulphur and replacement is required.

A schematic drawing of a typical iron sponge scrubber is provided in Figure 5. As shown in this drawing, the scrubbing medium is generally supported on grating or a plenum installed near the base of the vertical scrubbing vessel. The untreated gas enters the top of the vessel, moving down through the scrubbing medium. The treated gas exits the vessel through an outlet pipe installed below the plenum. McKinsey Zicari (2003) provides the general design guidelines outlined in Table 2.

As shown in Figure 6, a stainless steel vessel, previously used in a commercial cheese making process, was purchased and modified for use as a scrubber vessel, for the purpose of this trial.

Table 2. Iron sponge scrubber design recommendations (McKinsey Zicari, 2003).

Design feature	Recommendation
Vessels	Stainless-steel box or tower geometries are recommended for ease of handling and to prevent corrosion. Two vessels, arranged in series are suggested to ensure sufficient bed length and ease of handling (Lead/Lag).
Gas Flow	Down-flow of gas is recommended for maintaining bed moisture. Gas should flow through the most fouled bed first.
Gas Residence Time	A residence time of greater than 60 seconds, calculated using the empty bed volume and total gas flow, is recommended.[1]
Temperature	Temperature should be maintained between 18° C and 46° C in order to enhance reaction kinetics without drying out the media.[2]
Bed Height	A minimum 3 m (10 ft) bed height is recommended for optimum H_2S removal. A 6 m bed is suggested if mercaptans are present.[3] A more conservative estimate recommends a bed height of 1.2 to 3 m.[4]
Superficial Gas Velocity	The optimum range for linear velocity is reported as 0.6-3 m/minute.[3]
Mass Loading	Surface contaminant loading should be maintained below 10 g S/min/m^2 bed.[4]
Moisture Content	In order to maintain activity, 40% moisture content, plus or minus 15%, is necessary. Saturating the inlet gas helps to maintain this.[2]
pH	Addition of sodium carbonate can maintain pH between 8-10. Some sources suggest addition of 16 kg sodium carbonate per m^3 of sponge initially to ensure an alkaline environment.[2]
Pressure	While not always practiced, 140 kPa is the minimum pressure recommended for consistent operation.[3]

Sources:
[1] Revell (2001), [2] Kohl and Neilsen (1997), [3] Anerousis and Whitman (1985), [4] Maddox and Burns (1968),
[5] Taylor (1956)

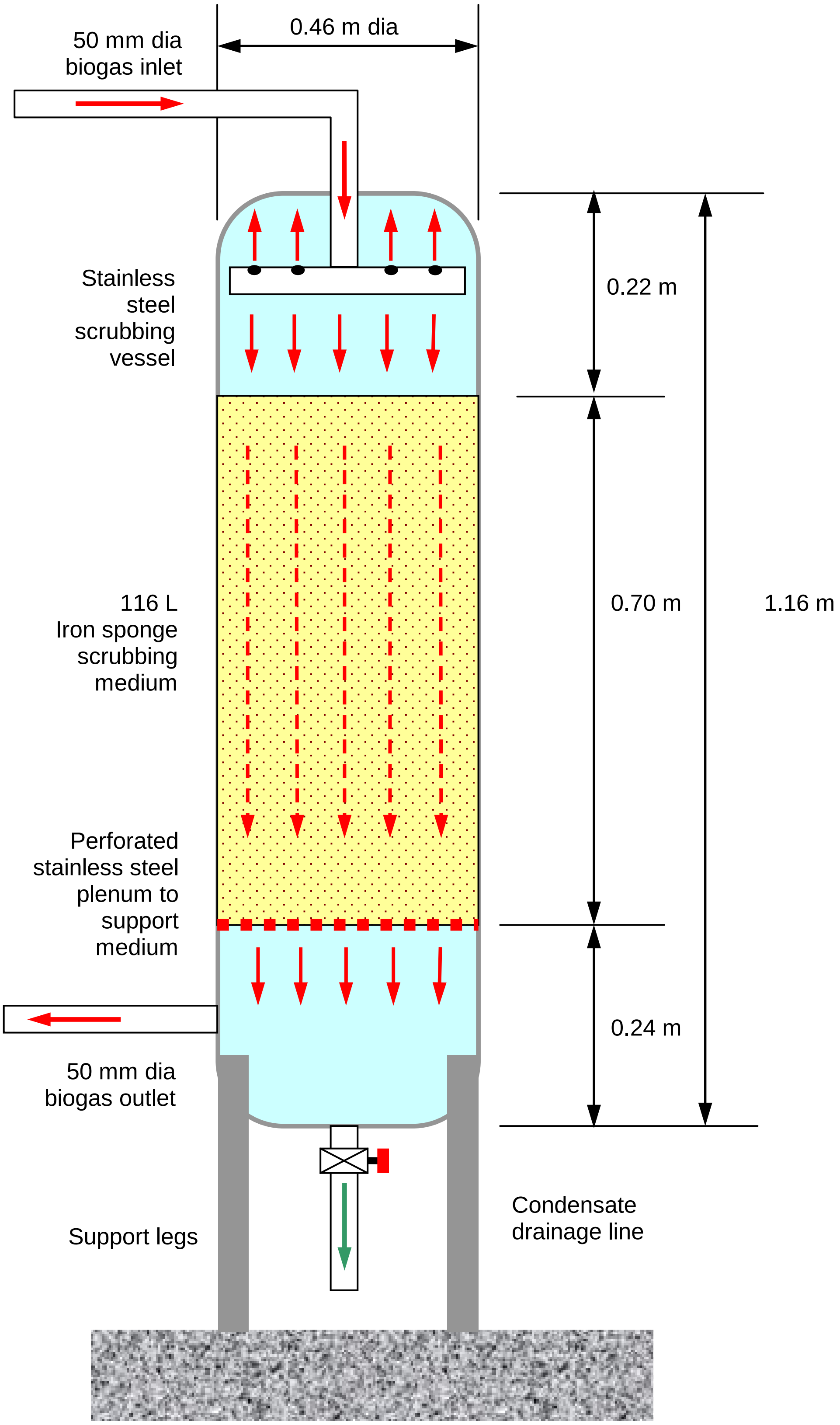

Figure 5. Schematic drawing of the iron sponge scrubber.

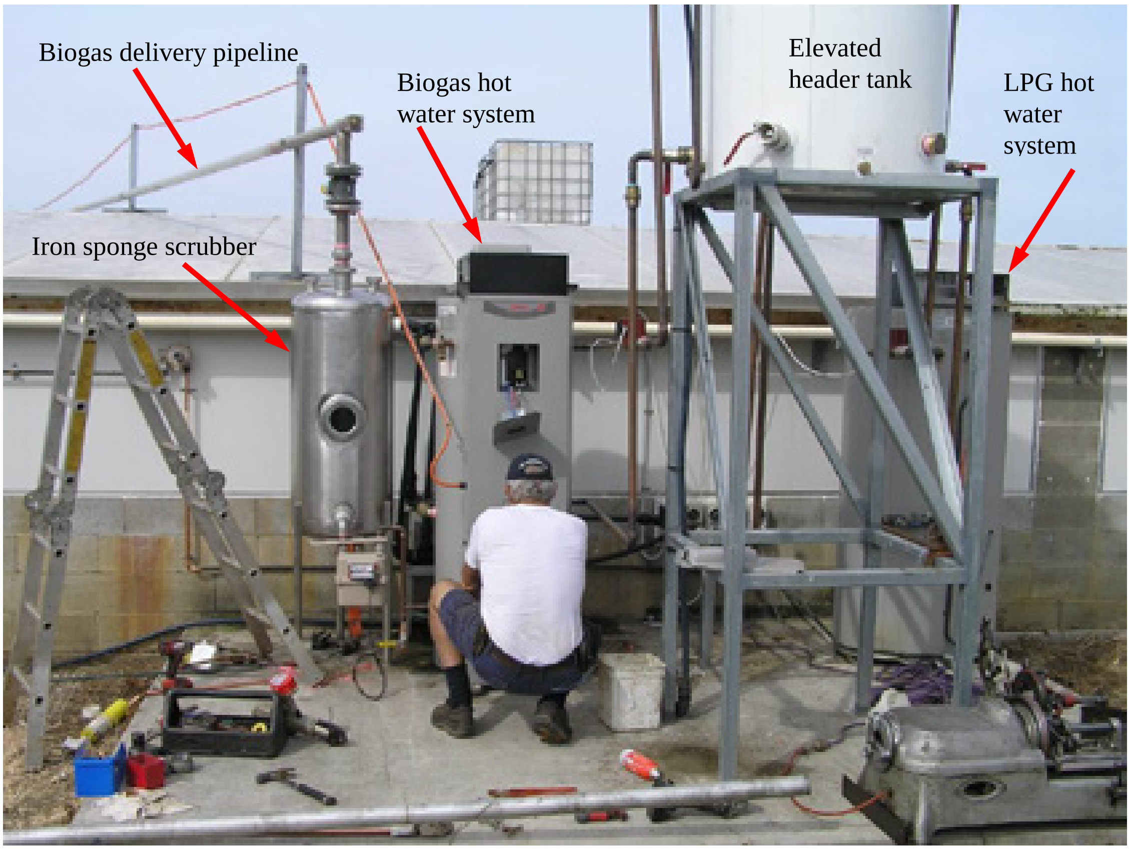

Figure 6. Photograph showing the iron sponge scrubber and biogas hot water system during installation.

As noted previously, SULFA-BIND® is a proprietary H_2S adsorption medium developed as an improved alternative to traditional iron sponge material. Sixty kg (46.15 L) of this product was purchased from Sulfide Control Pty Ltd (Churchill, Victoria, 3842) at a cost of $1716 (incl GST) delivered to Toowoomba, for trial during this research project. This was all of the product available in Australia at the time. It was considered that this quantity should be sufficient to compare the performance of this product against other scrubbing media over a short-term trial. The manufacturer's manual for the use of this product is provided in the Appendix to this report and a photograph of the medium is provided Figure 7. A short description of the product taken from the product manual is provided below:

> SULFA-BIND® is a granular, free-flowing natural mineral which has been impregnated with a ferric hydroxide (iron) coating and is used to adsorb hydrogen sulfide (H_2S) from biogas, landfill gas and contaminated air streams. Installed in fixed bed scrubber vessels or towers, the gas or air stream is passed through the media bed where the hydrogen sulfide is adsorbed onto the media and converted to elemental sulfur.
>
> SULFA-BIND® consists of a natural mineral, calcined to increase hardness, porosity, and surface area, with ferric hydroxide coating applied. When used for scrubbing sour gases, the coating reacts with H_2S to produce ferrous sulfide (and in the process changes color from orange to black– a useful visual indicator of the rate of saturation of the media). It provides up to 99.98% reduction of H_2S in biogas, and also removes malodorous mercaptans. It does not target methane, allowing this valuable product to pass through to be used as fuel in boilers, engines and turbines.

Figure 7. A photograph of the SULFA-BIND® proprietary H_2S adsorption medium to be trialled in the down-flow biogas scrubber.

The chemical reactions in the SULFA-BIND treatment process are outlined in the following description adapted from the product manual:

> H_2S is stripped from the gas stream according to the following chemical reactions. The ferric hydroxide coating on SULFA-BIND® reacts with H_2S:
>
> $2Fe(OH)_3 + H_2S \rightarrow 2Fe(OH)_2 + 2H_2O + 1/8\ S_8$
>
> $2Fe(OH)_2 + 2H_2S \rightarrow 2FeS + 4H_2O$
>
> This reaction results in the creation of ferrous sulphide, which turns the media black.
>
> Ferrous sulphide can be converted back to ferric hydroxide as follows:
>
> $2FeS + 3/20_2 + 3H_2O \rightarrow 2Fe(OH)_3 + 1/4S_8$
>
> This reaction is created by blowing ambient air through the media bed. Oxygen converts the FeS to ferric hydroxide and elemental sulphur that stays attached to the media. Visual observation during regeneration shows the media turning to its original orange colour with small sulphur particles attached.

The cumulative H_2S adsorption capacity of SULFA-BIND® is depicted in Figure 8 over 15 regeneration cycles (ADI International Inc).

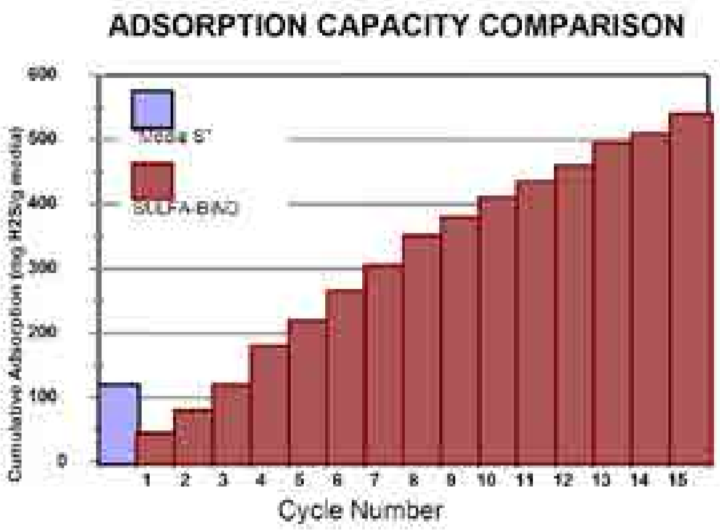

Figure 8. SULFA-BIND® H_2S cumulative adsorption capacity over 15 regeneration cycles (ADI International Inc, Canada).

Biogas quality monitoring

It was originally intended to evaluate the scrubber performance, in terms of the reduction in biogas H_2S concentrations, using the Teledyne Chemiluminescence H_2S analyser based at the DAFF (Qld) Toowoomba air quality laboratory. This instrument was temporarily mounted in a trailer to carry out an initial on-site analysis of the Grantham piggery biogas in November 2009. The analysis results suggested a biogas H_2S concentration of approximately 1000 ppm (0.1%). Photographs of this equipment are provided in Figures 9 and 10. The H_2S concentrations recorded over the 2 hour sampling period are plotted in Figure 11.

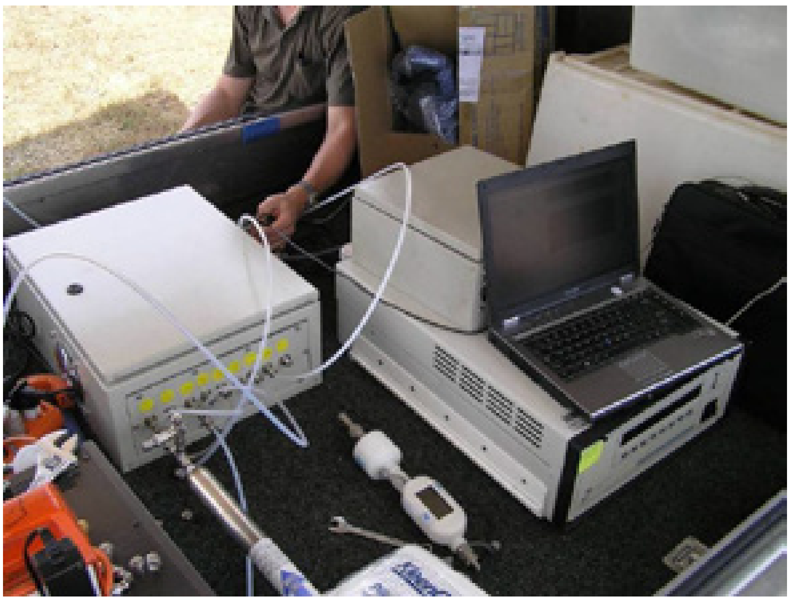

Figure 9. Initial on-site biogas analysis using a Teledyne Chemiluminescence H_2S analyser installed in trailer.

Figure 10. Initial on-site biogas analysis using a Teledyne Chemiluminescence H_2S analyser installed in trailer.

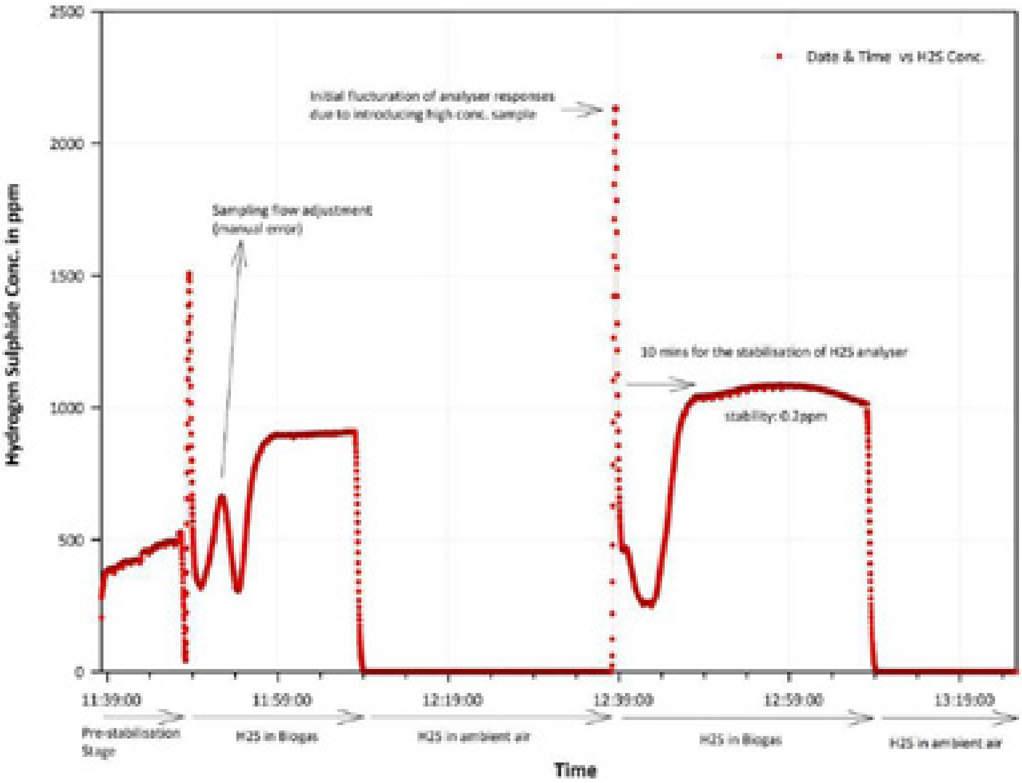

Figure 11. Hydrogen sulphide (H_2S) concentrations recorded during the initial on-site biogas analysis using the Teledyne Chemiluminescence H_2S analyser installed in trailer.

While the Teledyne Chemiluminescence H_2S analyser provided satisfactory results, a Geotech Biogas Check portable gas analyser, as shown in Figure 12, was purchased in June 2011, to enable convenient, regular monitoring of the biogas quality and scrubber performance. The portable analyser measures methane and carbon dioxide by infra-red absorption, oxygen by an electrochemical cell and hydrogen sulphide by an electrochemical cell installed in an external gas pod. This instrument can be used to measure gaseous concentrations at any of the several tapping points installed along the biogas train, including at the scrubber entry and discharge points. These measurements will be carried out on a regular basis to assess the ongoing performance of the scrubber.

Figure 12. Geotech Biogas Check portable gas analyser used to monitor biogas quality and scrubber performance.

Removal of Water Vapour

Krich *et al* (2005) provide the following discussion on technologies for the removal of water vapour from biogas:

> Because the biogas from the covered pond is collected from headspace above a liquid surface, the gas is generally saturated with water vapour. The amount of saturated water vapour in the gas depends on temperature and pressure. Biogas typically contains 10% water vapour by volume at 43°C, 5% by volume at 32°C, and 1% by volume at 4°C (Weast, 1958). The removal of water vapour (moisture) from biogas reduces corrosion that resulting from the condensation of water vapour within the system. Moisture removal is especially important if the H_2S has not been removed from the biogas because the H_2S and water vapour react to form sulphuric acid (H_2SO_4), which can result in severe corrosion in pipes and other equipment that comes into contact with the biogas. Even if the H_2S has been removed, water vapour can react with CO_2 to form carbonic acid (H_2CO_3), which is also corrosive (pH near 5). When water vapour condenses within a system due to pressure or temperature changes, it can result in clogging of the pipes and other problems as well as corrosion.

A number of techniques can be used to remove condensation from a pipe, including tees, U-pipes, or siphons. The simplest method to remove condensation water is to install horizontal pipe runs with a slope of 1:100. A drip trap or condensate drain can then be located at all low points in the piping to remove condensation. However, this will only remove water vapour that condenses in the piping. The simplest means of removing excess water vapour to dew points that preclude downstream condensate in biogas is through refrigeration. In a refrigerator unit, water vapour condenses on the cooling coils and is then captured in a trap. The dew point of biogas is close to 1.7°C.

The biogas system at the Grantham piggery is fitted with several condensation drainage points which are released on a daily basis. All biogas pipelines have been installed with a minimum gradient of 2% to facilitate adequate drainage towards the drainage points.

Piggery shed heating

The piggery currently uses approximately 40,000 L of LPG annually, at a cost of $30,000, for heating farrowing pads by the circulation of hot water. A new Rheem Model 631265NO heavy duty gas hot water system (HWS) designed to run on natural gas, was installed beside a similar, existing LPG fired unit, during April 2012. The manufacturer's performance details for this HWS are provided in Table 3.

Table 3. Manufacturer's technical gas performance details for Rheem Model 631265NO heavy duty gas hot water system converted to operate on biogas.

Gas Type:	Units	Nat/SNG	Propane	Butane
Thermal Input	MJ/h	110	100	95
Output	kW	23.8	21.7	20.6
Min. Gas Supply Pressure	kPa	1.13	2.75	2.75
Test Point Pressure	kPa	0.85	2.50	2.50
Max. Gas Supply Pressure	kPa	3.5	3.5	3.5

Following the connection of the Stage 2 gas delivery pipeline, the new HWS was converted to run on biogas by Williamson Brothers gas fitters. This involved adjusting the burner pressure at the inlet regulator, drilling out the main jet from 4.8 mm to 6.0 mm and making minor adjustments to the mixture (interrupter) screw on the burner throat. An exhaust gas analyser was used to assess the combustion efficiency of the converted HWS burner.

In Queensland, the offer for sale, installation or use of Type A and Type B gas devices can only occur if the device has been approved by the Chief Inspector or by a person or body approved by the Chief Inspector under s733(2) *Petroleum and Gas (Production and Safety) Act 2004*. The converted biogas HWS received Australian Gas Association (AGA) certification and a certificate of conformity was issued, as required under the legislation.

The underfloor heating system in the piggery farrowing sheds was installed by the piggery owners during 2010. Diameter 15 mm copper pipe was bent into an 'S' shape ready for installation in concrete heating pads cast into the floors of each farrowing pen, as shown in Figure 13 The concrete pads were formed by removing some of the plastic tiles and installing a plywood base. The copper pipe 'S' sections are joined (in series) using flexible polybutylene hot water pipe and fittings (Hepworth Hep$_2$O). A circulation pump is used to circulate hot water from the elevated hot water header tank through approximately 30 under-floor heating pads per circulation line. The heating pad temperature was regulated to achieve a target pad temperature is 32 - 34°C by adjusting a valve on each recirculation line. The thermostats on the hot water systems are set at 60 - 65°C.

During the system commissioning stage, the pad temperatures were monitored using an infrared thermometer. The heated pads provide comfort and optimal growing conditions for the piglets housed in the farrowing sheds without overheating the sows. A photograph of an operational farrowing pad is provided in Figure 14. A schematic drawing of the hot water circulation system is provided in Figure 15.

Figure 13. Typical copper pipe 'S' shaped section prior to pouring one of the concrete heating pads in the piggery farrowing sheds.

Figure 14. Farrowing pen at the Grantham piggery showing one of the concrete pads heated by circulating hot water through copper pipes cast into the pad.

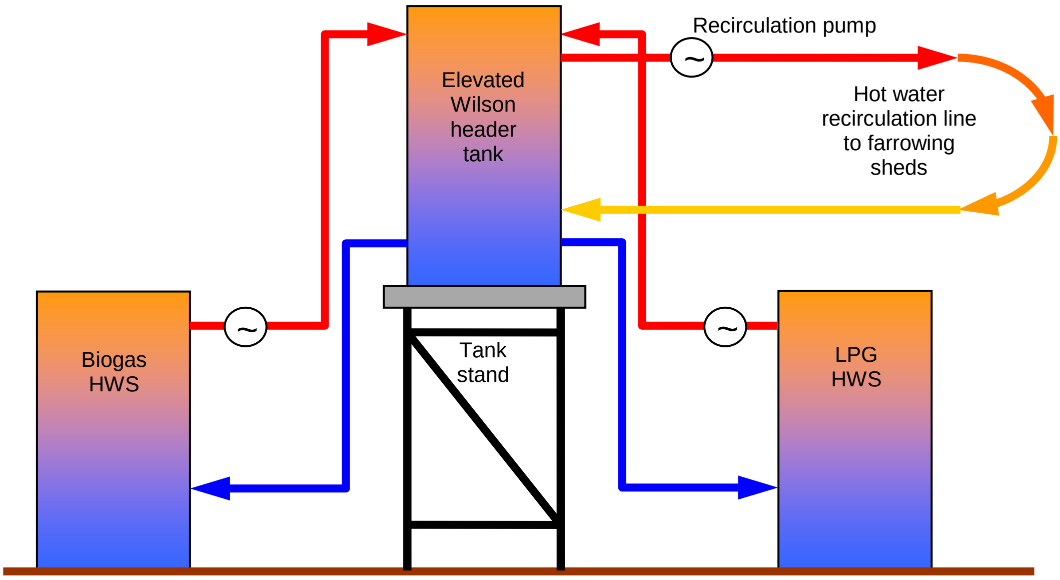

Figure 15. Schematic drawing of hot water recirculation system used to heat farrowing sheds.

Piggery energy audit

As reported by Skerman *et al* (2011), an energy audit was carried out for the Grantham piggery over the 12-month period from April 2009 to March 2010. The results are summarised in Figure 16 which shows the electricity and liquid petroleum gas (LPG) energy usage at the piggery over this period.

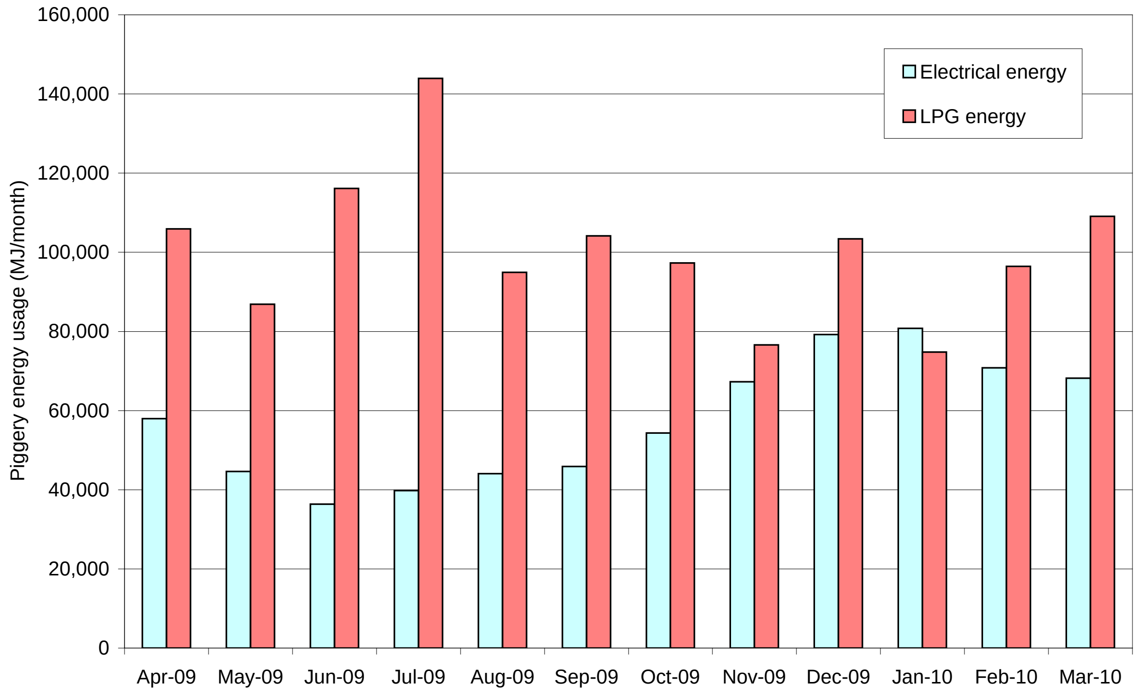

Figure 16. Results of an energy audit carried out for the Grantham piggery for the 12-month period from April 2009 to March 2010.

Electricity is used to drive large cooling fans installed on the end walls of the piggery sheds. From Figure 16, it is clear that the peak electricity use occurred during the hot summer months while the LPG usage for the underfloor heating system in the farrowing sheds increased substantially during the cool winter months.

During the audit period, the piggery consumed 48,000 L of LPG at a cost of $44,000 (average 92c/L). The energy value of this LPG was 1210 GJ/year, representing 64% of the total piggery energy usage.

Skerman *et al* (2011) estimated that 587 GJ/year of primary (heat) energy could be provided by biogas. This represents approximately half of the LPG consumption and a potential cost saving of $23,000 per year providing the biogas can be used successfully as a substitute for some of the LPG. These estimates were based on averaging the biogas production and heating demand over the year. In reality, it might not be possible to achieve this saving due to the seasonal nature of the biogas production and heating demand.

The total electricity usage over the 12 month audit period was 689 MJ/year (191,495 kW.hr/year) at a cost of $32,000/year (average 17c/kW.hr). Electricity accounts for 36% of the total piggery energy usage.

As an alternative to using all of the available biogas energy for underfloor shed heating, it may be feasible to use the biogas to run a combined heat and power (CHP) system consisting of an electrical generator driven by an internal combustion engine fitted with heat exchangers on the engine cooling system and exhaust to reclaim otherwise wasted heat energy.

The calculator printout in Figure 17 indicates that the available biogas could be used to generate 48,883 kW.hr/year of electrical power, based on a 30% electrical power generation efficiency. This represents 26% of the total piggery electrical power usage at a value of $8300/year, based on an electricity cost of 17c/kW.hr. In addition to the electrical power generation, 50% of the waste heat from the generator (293 GJ/year) could be reclaimed by heat exchangers for use in the underfloor heating system. In terms of LPG replacement, this reclaimed heat could have a value up to $11,497/year.

Due to delays in the installation of stages 1 and 2 of the biogas system, it was not possible to consider trialling a CHP system at the piggery. Depending on seasonal biogas generation, it may be feasible to install an internal combustion engine driven electrical generator of approximately 20 kW output capacity, which could potentially be run for several hours per day during the warmer months when the gas generation rate is likely to be higher and farrowing pen heating requirements are lower. It will only be possible to make a definitive decision on the feasibility of installing a CHP system after a reasonable period of water heating records become available.

Piggery biogas energy calculator

Draft Version 1.3, Nov 2011

Developed by: Alan Skerman, Agri-Science Queensland

Piggery / producer name: GNPH Palahra piggery

Piggery locality: Grantham

Parameter	Units	Value	Range	Reference
Piggery operating capacity	SPU	1,265		
Volatile solids (VS) production	kg VS/SPU/yr	90.91		PigBal
Standard piggery volatile solids (VS) production	kg VS/day	315		PigBal standard values
Estimated piggery volatile solids (VS) production	kg VS/day	315		
Volatile solids removal in solids separator	%	0%	0 - 25%	
Biogas production rate	m^3/kg VS added	0.32	0.26 - 0.38	NIWA, 2008
Daily biogas production	m^3 biogas/day	101		
Proportion of biogas captured by pond cover	%	63%	100% for fully covered pond	
Daily biogas collection	m^3/day	63		
Biogas methane %	%	75%	55 - 70%	NIWA, 2008
Daily methane collection	m^3 CH_4/day	48		
Annual methane collection	m^3 CH_4/year	17,356		
Methane energy value	MJ/m^3 CH_4	33.8		NIWA, 2008
Energy value	MJ/day	1,606		
Unit conversion	MJ/kW hr	3.6		
Total primary energy potential	kW.hr/day	446		
Total primary power potential	kW	18.6		
Carbon credit value				
Estimated CO_2 emission abatement	t CO_2 -e/year	247		DCCEE, 2011
Carbon credit value	\$/t CO_2 - e	\$23		
Estimated annual carbon credit value	\$/year	\$5,687		
Water heating potential				
Assumed boiler conversion efficiency	%	100%		NIWA, 2008
Hourly primary energy (heating) potential	MJ/hr	67		
Daily primary energy (heating) potential	kW.hr/day	446		
Annual primary energy (heating) potential	kW.hr/yr	162,945		
LPG energy value	MJ/m^3 (liquid)	25,000		LPG Homegas
LPG required to replace biogas	L/yr	23,464		
Average LPG cost	\$/L	\$0.98		
Value of biogas as LPG heating substitute	\$/yr	\$22,995		
Combined heat and power (CHP) potential				
Generator electrical efficiency	%	30%		NIWA, 2008
Daily electricity generation	kW.hr/day	134		
Annual electricity generation	kW.hr/yr	48,883		
Minimum generator size (continuous operation)	kW	5.6		
Average electricity cost	\$/kW.hr	\$0.17		
Value of generated electricity	\$/yr	\$8,310		
Generator heat recovery efficiency	%	50%		NIWA, 2008
Hourly heating potential	MJ/hr	33		
Daily heat generation	kW.hr/day	223		
Annual heat generation	kW.hr/yr	81,472		
LPG required to replace biogas	L/yr	11,732		
Value of biogas as LPG heating substitute	\$/yr	\$11,497		
Total value of electricity and heat	\$/yr	\$19,808		

References:

NIWA (National Institute of Water & Atmospheric Research), 2008, Covered Anaerobic Ponds for Anaerobic Digestion and Biogas Capture: Piggeries, NIWA Information Series No 32, 2008, NIWA New Zealand.

Figure 17. Draft DAFF Queensland Piggery biogas energy calculator printout for the Grantham piggery, based on April 09 to March 10 occupancy.

Results

Biogas composition monitoring

The results of the biogas composition monitoring to date are provided in Table 4. These results were obtained using a Geotech Biogas Check portable gas analyser. The average methane, carbon dioxide and hydrogen sulphide concentrations were 69%, 30% and 1637 ppm respectively.

Table 4. Biogas analysis results obtained using the Geotech Biogas Check portable gas analyser.

Date / time	Sample Location	CH_4 %	CO_2 %	O_2 %	Balance %	H_2S ppm	CH_4/CO_2 %
20/03/2012 14:43	Biogas filter	69.7	30.1	0.0	0.2	1236	2.32
20/03/2012 14:46	Biogas filter	70.6	29.3	0.0	0.1	1270	2.41
20/03/2012 14:49	Biogas filter	69.9	30.0	0.0	0.1	1177	2.33
20/03/2012 14:52	Biogas filter	70.0	29.9	0.0	0.1	1123	2.34
27/03/2012 14:56	Biogas filter	71.5	28.3	0.1	0.1	1572	2.53
27/03/2012 14:58	Biogas filter	71.2	28.7	0.0	0.1	1570	2.48
27/03/2012 15:01	Biogas filter	71.6	28.3	0.0	0.1	1589	2.53
23/04/2012 13:52	Biogas filter	66.6	32.3	0.4	0.7	1970	2.06
23/04/2012 13:54	Biogas filter	67.9	31.6	0.4	0.1	2172	2.15
23/04/2012 13:56	Biogas filter	67.3	32.2	0.4	0.1	2127	2.09
23/04/2012 13:58	Biogas filter	67.3	32.2	0.3	0.2	2143	2.09
8/05/2012 10:54	High pressure switch	67.9	31.6	0.4	0.1	1659	2.15
8/05/2012 10:56	High pressure switch	68.5	31.1	0.3	0.1	1647	2.20
8/05/2012 10:58	High pressure switch	68.0	31.6	0.3	0.1	1581	2.15
8/05/2012 11:15	Biogas filter	66.5	28.3	1.1	4.1	1685	2.35
8/05/2012 11:18	Biogas filter	67.3	29.0	1.1	2.6	1649	2.32
8/05/2012 11:21	Biogas filter	67.3	28.5	1.1	3.1	1654	2.36
Average:		**68.8**	**30.2**	**0.3**	**0.7**	**1,637**	**2.29**

Scrubber design

Following conversion of the Rheem hot water system to run on biogas, the biogas flowrate through the system was measured at 3.8 m^3/hr. This is 40% higher than the 2.7 m^3/hr average biogas yield from the covered pond reported by Skerman *et al* (2011) over a 9 month monitoring period (April to December 2009). Based on these results, it is expected that there will be sufficient biogas available to supply the HWS for the majority of the time.

The parameters used in the design of the biogas scrubber are outlined in Tables 5 and 6.

Table 5. Biogas scrubber design parameters (iron sponge and SULFA-BIND® options)

Parameter	Units	Values	Reference / Notes
Average covered pond biogas yield	m^3/day m^3/hr	65 2.7	Skerman (2011)
Hot water system biogas consumption rate	m^3/hr	3.8	Measured data
Average biogas H_2S concentration	ppm vol mole H_2S/m^3 g H_2S/m^3	1637 0.0681 2.3193	Table 4 at 101.3 kPa & 20°C
Average H_2S load	kg H_2S/day	0.1508	
Average sulphur load	kg S/day g S/min	0.1418 0.0985	
Fe_2O_3 stoichiometric H_2S removal	kg H_2S/kg Fe_2O_3	0.640	
Iron sponge			
Assumed iron sponge H_2S removal efficiency	% (factor of safety)	67% (1.5) 85% (1.18)	Walsh et al (1988) McKinsey Zicari (2003)
Required iron sponge Fe_2O_3 mass	kg Fe_2O_3/day	0.353	Based on 67% efficiency
Typical iron sponge density	lb Fe_2O_3/bushel sponge kg Fe_2O_3/m^3 sponge	15 190	McKinsey Zicari (2003)
Required iron sponge volume	L sponge/day L sponge/year	1.86 679	
Required iron sponge mass	kg sponge/day kg sponge/year	1.49 679	
Trial scrubber iron sponge volume	L	116	
Trial scrubber iron sponge mass	kg	93	
Expected iron sponge life	days	63	
SULFA-BIND® H_2S adsorption media			
Adsorption rate	mg H_2S/g Sulfa-Bind	35	Manufacturer's data
Required Sulfa-Bind mass	kg Sulfa-Bind/day	4.307	
Sulfa-Bind mass density	kg Sulfa-Bind/L	1.3	Manufacturer's data
Required Sulfa-Bind volume	L Sulfa-Bind/day	3.31	
Available Sulfa-Bind mass	kg Sulfa-Bind	60	
Available Sulfa-Bind volume	L Sulfa-Bind	46.15	
Sulfa-Bind lifespan (before regeneration)	days	14	

Table 6. Biogas scrubber design evaluation in comparison to published recommendations (iron sponge and SULFA-BIND® options).

Stainless steel scrubbing vessel	Units	Value	Recommended value	Reference
Diameter	m	0.46		
Max media height	m	0.70	1.2 – 3.0	McKinsey Zicari (2003)
Cross-sectional area	m^2	0.166		
Total vessel volume	L	167.85		
Max media volume	L	116.33		
HWS gas usage				
Water heater gas consumption	MJ/hr	96.51		
Methane energy value	MJ/m^3 CH_4	36		
Biogas CH_4 content	%	70%		
Max biogas flowrate	m^3 biogas/hr	3.83		
	m^3 biogas/day	91.91		
Max biogas velocity in vessel	m/min	0.38	0.6 - 3.0	McKinsey Zicari (2003)
Scrubber design criteria				
Average S production	g S/day	141.84		
S loading	g S/min	0.0985		
	g S/min/m^2 bed	0.5927	10	McKinsey Zicari (2003)
Sulfa-bind				
Volume available	L	46.15		
Media depth	m	0.278		
Residence time	min	0.72	> 1 minute	McKinsey Zicari (2003)
Iron sponge				
Average S production	g S/day	141.84		
Media depth	m	0.7		
Residence time	min	1.82	> 1 minute	McKinsey Zicari (2003)

Implications

Federal Government estimates at the time of the recent CFI methodology launch indicated that there are approximately 690 piggeries in Australia which could potentially implement biogas collection and flaring/use systems. Without the implementation of abatement measures, piggery emissions are expected to be 1.3 Mt CO_2-e by 2020. It is estimated that an emission abatement of around 50% of this figure could be achieved through the installation of biogas collection and flaring/use systems, in accordance with the CFI methodology.

In systems where the biogas is used as an energy source for shed heating and/or electrical power generation, further reductions in GHG emissions will result, along with savings in energy costs.

This level of uptake by industry will not be achieved unless producers have confidence in the available technology and likely economic returns. The outcomes of this project have contributed to a reduction in risk associated with the adoption of the CFI methodology, particularly for smaller scale producers who may not be able to afford to employ specialist consultants and contractors to carry out the required design and installation.

In addition to GHG abatement, if Australian intensive livestock producers are going to benefit from the significant energy resources and resulting cost savings available from the collection of biogas, they will need practical guidance on the selection and use of technologies for treating the biogas to an appropriate standard to enable effective use of the biogas. These technologies must be robust, cost effective, and relatively simple to operate with minimal labour, while requiring minimal input of specialised chemicals.

The technologies developed and evaluated in this project were selected to meet these criteria. Following the conclusion of the proposed performance monitoring period in June 2013, it is anticipated that the resulting findings will provide valuable guidance for intensive livestock producers contemplating the installation of biogas capture and use systems.

Conclusions

Recent untreated biogas composition data recorded at the Grantham piggery, suggests average methane, carbon dioxide and hydrogen sulphide concentrations of 69%, 30% and 1637 ppm, respectively. The average methane concentration is consistent with the data reported by Skerman *et al* (2011). Due to its corrosive nature, the average hydrogen sulphide concentration suggests that use of the untreated biogas would have adverse effects on the life expectancy of appliances such as hot water boilers, internal combustion engines, Stirling engines and fuel cells. This highlights the need for a robust, relatively simple, cost effective scrubber to remove a significant proportion of the hydrogen sulphide from the biogas.

It is anticipated that a dry scrubbing method using iron sponge media (or a more recently developed commercial product) to adsorb H_2S from the biogas stream will prove to be the most suitable technology for adoption in small to medium sized intensive livestock production facilities. Commercial scrubbing media and lower cost alternatives will be further evaluated over a minimum 12 month period to determine the most cost effective approach.

Recommendations

Delays in the installation of the biogas scrubber and shed heating system at the Grantham piggery severely curtailed opportunities to monitor the performance of the system.

To maximise the benefits resulting from the significant investment already made in establishing the facilities at the Grantham piggery, it is recommended that the project contract be extended (at no additional cost) until June 2013, to enable the performance of the biogas scrubber and water heating system to be monitored for an additional 12 month period. The resulting data will assist in resolving outstanding technical and regulatory issues while providing producers with clear evidence of the potential benefits and costs associated with the installation and operation of biogas collection and use systems.

An addendum to this Final Report should be prepared following the conclusion of the extended monitoring period.

References

Abatzoglou, N. and Boivin, S., 2009. A review of biogas purification processes, Society of Chemical Industry and John Wiley and Sons Ltd, Biofuels, Bioproducts and Biorefining 3:42-71 (2009). http://onlinelibrary.wiley.com/doi/10.1002/bbb.117/pdf

ADI International Inc., PowerPoint Presentation: Hydrogen Sulfide Removal Using Ferric Hydroxide Adsorbent, SULFA-BIND®, www.adi.ca
http://www.apcas.qc.ca/2006042011h00Hum.pdf

Anerousis, J. P. and Whitman, S. K., 1985. Iron Sponge: Still a Top Option for Sour Gas Sweetening, Oil and Gas Journal February 18: 71-76.

Capstone Turbine Corporation, 2002. C30 Biogas Spec-Sheet . Chatsworth, CA: 3 p. www.microturbine.com/documents/specsheetlandfill.pdf.

DCCEE (Department of Climate Change and Energy Efficiency), 2011. Carbon Farming Initiative: Methodology for the destruction of methane generated from manure in piggeries, Approved. http://www.climatechange.gov.au/government/initiatives/carbon-farming-initiative/methodology-development/approved-methodologies/~/media/government/initiatives/cfi/methodology-development/methodologies-under-consideration/CFI-MethanePiggeriesMethodology-20111205-PDF.pdf

Gas Processors Suppliers Association, 2004. Engineering data book, 12th Edition FPS, Volumes I & II, Sections 1-26, Gas Processors Suppliers Association, Tulsa, Oklahoma 74145

Hagen, M., E. Polman, A. Myken, J. Jensen, O. Jönsson, AB Biomil, and A. Dahl. 2001. Adding gas from biomass to the gas grid. Final report, contract no: XVII/4.1030/Z/99-412. July 1999 – February 2001.
http://www.dgc.eu/pdf/altener.pdf

Powers, W., 2004. The Science of Smell Part 1: Odor perception and physiological response, Iowa State University, University Extension, PM 1963a
http://www.extension.iastate.edu/Publications/PM1963A.pdf

Jiuan, Y.L., 2005. Evaluation of wet scrubber systems, A dissertation submitted in fulfilment of the requirements of Courses ENG4111 & 4112 Research Project towards the degree of Bachelor of Engineering (Mechanical), University of Southern Queensland, Faculty of Engineering and Surveying. http://eprints.usq.edu.au/534/1/YAPLeeJiuan-2005.pdf.pdf

Kohl, A. and R. Neilsen, 1997. Gas Purification, Golf Publishing Company, Houston, Texas: 1395 p.

Krich K., Augenstein, D., Batmale, J. P., Benemann, J., Rutledge, B. and Salour, D., 2005. Biomethane from Dairy Waste - A Sourcebook for the Production and Use of Renewable Natural Gas in California, Prepared for Western United Dairymen, Funded in part through USDA Rural Development.
http://www.calstart.org/Libraries/Publications/Biomethane_from_Dairy_Waste_Full_Report.sflb.ashx

Kuria, J. and Maringa, M., 2008. Developing simple procedures for selecting, sizing, scheduling of materials and costing of small bio – gas units, International Journal for Service Learning in Engineering, Vol. 3, No. 1, pp. 9 - 40, Spring 2008, ISSN 1555-9033.

Maddox, R. N. and Burns, M. D., 1968. Iron-Oxide Process Design Calculations, Oil and Gas Journal 54 (August).

McKinsey Zicari, S., 2003. Removal of hydrogen sulphide from biogas using cow-manure compost, A thesis presented to the Faculty of the Graduate School of Cornell University in Partial Fulfilment of the Requirements for the Degree of Master of Science.
http://www.green-trust.org/Al%20Rutan/MS-Thesis-Steve-Zicari.pdf

Mears, D., 2001. Biogas Applications for Large Dairy Operations: Alternatives to Conventional Engine-Generators, Prepared under contract to Cornell Cooperative Extension Association of Wyoming County, Warsaw, NY. Final Edition.
http://www.manure.umn.edu/assets/cornell_biogas_applications.pdf

Noyola, A., Morgan-Sagastume, J.M. & Lopez-Hernandez, J.E., 2006. Treatment of biogas produced in anaerobic reactors for domestic wastewater: odor control and energy/resource recovery, Reviews in Environmental Science and Bio/Technology (2006) 5:93–114 _ Springer 2006, DOI 10.1007/s11157-005-2754-6

Perssson M., Jönsson O. and Wellinger A., 2006. Biogas Scrubbing to Vehicle Fuel Standards and Grid Injection, IEA, BioEnergy, 2006.
http://www.iea-biogas.net/_download/publi-task37/upgrading_report_final.pdf

Revell, C. (2001). Personal Communication with S. Zicari. Connelly-GPM, Inc., Chicago, IL.,

Saikkonen, K. A., 2006. Technical and economic feasibility of upgrading dairy manure-derived biogas for natural gas pipeline, A Thesis presented to the Faculty of the Graduate School of Cornell University In Partial Fulfilment of the Requirements for the Degree of Master of Science.

Skerman, A., Collman, G., and Pott, L., 2011. Biogas production by covered lagoons – QNPH piggery, Grantham Qld, Final Report - RIRDC Project No PRJ-003003, RIRDC, Barton, ACT.

STM Power, 2002. Pure Energy on Demand, Brochure for STM Stirling Engines.
STM Power, Ann Arbor, MI: 6 p.
www.stmpower.com/Markets/STM. PureEnergyBrochure.pdf

Tanaka, Y., 2002. A dual purpose packed-bed reactor for biogas scrubbing and methane-dependent water quality improvement applying to a wastewater treatment system consisting of UASB reactor and trickling filter, Bioresource Technology 84 (2002) 21–28
http://www.sciencedirect.com/science/article/pii/S0960852402000317

Taylor, D. K., 1956. "Natural Gas Desulfurization (Parts 1-4)." Oil and Gas Journal (November 5, 19, and December 3, 10): 4 p.

Walsh, J.L., Ross, C.R., Smith, M.S., Harper, S.R. and Wilkins, W.A., 1988. Handbook on biogas utilisation, Published by the Environment, Health and Safety Division, Georgia Tech Research Institute, Atlanta, Georgia, for US Department of Energy
http://infohouse.p2ric.org/ref/22/21262.pdf

Wellinger, A. and Linberg A., 2000. Biogas Upgrading and Utilization - IEA Bioenergy Task 24: Energy from biological conversion of organic wastes. International Energy Association, Paris, France
http://www.iea-biogas.net/_download/publi-task37/Biogas%20upgrading.pdf

Wiedemann, S., McGahan, E., Grist, S. and Grant, T., 2010. Environmental Assessment of Two Pork Supply Chains Using Life Cycle Assessment, RIRDC Publication No 09/176, RIRDC Project No PRJ-3176 and PRJ-4519
https://rirdc.infoservices.com.au/downloads/09-176.pdf

XENERGY, Inc., 2002. Toward a Renewable Power Supply: The Use of Bio-Fuels in Stationary Fuel Cells. Prepared for the Northeast Regional Biomass Program, Washington, D.C.: 63 p.

Appendix

SULFA-BIND® Hydrogen Sulphide Removal From Biogas, Landfill Gas, and Air Streams

ADI International, 1133 Regent Street, Fredericton, NB E3B3Z2 Canada, www.adi.ca
Phone: (506) 452-9000
Fax: (506) 459-3954
January, 2009

What is SULFA-BIND®?

SULFA-BIND® is a granular, free-flowing natural mineral which has been impregnated with a ferric hydroxide (iron) coating and is used to adsorb hydrogen sulfide (H_2S) from biogas, landfill gas and contaminated air streams. Installed in fixed bed scrubber vessels or towers, the gas or air stream is passed through the media bed where the hydrogen sulfide is adsorbed onto the media and converted to elemental sulfur.

Virtually every wastewater treatment plant and landfill produces off-gas (i.e., “biogas”); these gases are often high in hydrogen sulfide concentration. Hydrogen sulfide is highly toxic and odorous, and its release to atmosphere is carefully monitored and regulated. It is also a very corrosive substance, which can result in costly damage to piping and equipment used in biogas handling and co-generation systems. One common means of dealing with this is to flare the biogas, which converts hydrogen sulfide to sulfur dioxide; however, typical conversion rates are only in the range of 95%, which in many cases is not sufficient to meet stringent air quality regulations. In addition, excessive sulfur dioxide emissions may be created. Where greater H_2S removals are required, or in cases where flaring is not possible because the biogas is to be used as fuel in boilers or electrical generators, a SULFA-BIND® adsorber is an ideal alternative.

SULFA-BIND® consists of a natural mineral, calcined to increase hardness, porosity, and surface area, with ferric hydroxide coating applied. When used for scrubbing sour gases, the coating reacts with H_2S to produce ferrous sulfide (and in the process changes color from orange to black– a useful visual indicator of the rate of saturation of the media). It provides up to 99.98% reduction

of H_2S in biogas, and also removes malodorous mercaptans. It does not target methane, allowing this valuable product to pass through to be used as fuel in boilers, engines and turbines.

The treatment process consists of downflow or upflow of gas through a fixed bed of SULFA-BIND®. Required residence time within the bed is somewhat dependant upon H_2S concentration, but is generally about 60 seconds. Proper performance requires that the media be maintained in a moist condition; since most biogas is naturally saturated with water vapor, this condition is usually satisfied without the need for addition of water. Excess water resulting from condensation within the bed should be drained off on a regular basis. The ferric hydroxide coating is firmly fixed to the surface of the media particles, and will not be washed off by this water.

Upon saturation with sulfide, the media can be regenerated by blowing air through the media bed, during which the sulfide is converted to elemental sulfur and the media coating is converted to its original ferric hydroxide form (and returns to its original orange color). Up to a dozen regenerations are possible, by which time the media will have adsorbed 40% to 50% of its weight in sulfur.

Continuous (rather than batch) regeneration is also possible, if the gas stream contains a small amount of air (~1%) and low hydrogen sulfide concentration. One important point about SULFABIND® is that, unlike some other adsorbents, it is completely non-flammable, with no risk of combustion due to the heat generated during the regeneration reaction.

Spent SULFA-BIND® passes the standard Toxicity Characteristic Leaching Procedure (TCLP) test, and is typically considered acceptable for non-hazardous landfill disposal (check with appropriate authorities regarding local disposal requirements).

SULFA-BIND® is a Trademark of ADI International Inc. Patented in Canada and United States.

SULFA-BIND® plant operating guide

The following is intended as a general guide to provide the reader with information on requirements for start-up, operation, and maintenance of a SULFA-BIND® process. It is not intended to be a detailed operation and maintenance manual such as would be provided as part of site-specific start-up training by ADI for each plant.

Installation

1. The filter vessel should contain a support grate "tray" at least 12" (30 cm) above the bottom of the filter vessel (the media will rest on top of this tray). Perforated gas distribution piping should be located in the open space below this tray.

2. Place the SULFA-BIND® into the scrubber on top of the support grating. SULFA-BIND® is shipped dry, therefore while adding the SULFA-BIND® to the scrubber, it is important that it be properly moistened to ensure peak performance. This can be accomplished by spraying the media with water from a garden hose as it is added to the vessel. Do not add too much or too little water – if the media is damp enough to hold its shape in a "clump" when squeezed in the hand, the moisture content is sufficient. If it breaks apart and separates into small fragments or blows away, it is too dry.

3. It is desirable to spread the media out evenly in the scrubber as it is poured in. Do not form large "cones" by pouring a large amount of media in one spot before spreading out; this could result in compaction, leading to channelling of gas flow. It is more important to ensure that the media is in proper contact with the sides of the scrubber, to prevent channelling of gas up the sides of the wall.

Normal Operation

Typically, gas is conveyed to the scrubber by means of a blower or fan. Scrubbers may be operated in upflow or downflow mode. Even distribution of the gas across the media bed will minimize channelling, which can be accomplished with perforated pipe grids.

It is desirable that the gas be saturated with water vapour to keep the media at the proper moisture content (in many installations, the gas is already saturated, but in some cases a spray head in the scrubber, or other means of adding water to the gas may be necessary). Any free liquid condensate accumulating inside the scrubber vessel should be drained periodically through a drain line at the bottom of the vessel. This drain line should run to a proper drip trap, which can be opened to drain liquid without allowing escape of gas.

Weekly (or if scrubber performance declines unexpectedly), the operator should take a "core" sample of the media by inserting a 1"(2.5 cm) diameter sharp-edged pipe as far as possible down through the media bed. One should then examine the media for moisture content. If the media appears to be drying out, then it should be moistened by spraying water on its surface.

The initial pressure drop through the scrubber should be 1" - 6" (2.5 - 15 cm) water column. However, over time, pressure drop may rise. This is to be expected, due to accumulation of sulphur within the scrubber bed. The operator should monitor the pressure gauge reading on the blower discharge. Rising pressure may be an indicator of approaching media saturation.

Hydrogen sulphide concentration in the outlet gas should be tested on a regular basis using a Draeger Tube gas tester, or similar device. Follow manufacturer's directions carefully.

It is very important that all liquid hydrocarbons be removed from the gas stream before entering the scrubber; these liquids will coat the surface of the media particles, resulting in greatly diminished performance. If liquid hydrocarbons are present in the gas, gas/liquid separators or demisters should be installed upstream of the scrubber. Consult the manufacturers of these devices for proper selection.

The chemical reactions, for the SULFA-BIND® process to work ® efficiently, are assisted with a small amount of oxygen present in the gas stream, typically 0.1% to 0.2% as oxygen. If no oxygen is present in the gas stream, an air compressor should be used to add 0.5% to 1% ambient air to the gas. H_2S is stripped from the gas stream according to the following chemical reactions. The ferric hydroxide coating on SULFA-BIND® reacts with H_2S as follows:

$2Fe(OH)_3 + H_2S \rightarrow 2Fe(OH)_2 + 2H_2O + 1/8\ S_8$

$2Fe(OH)_2 + 2\ H_2S \rightarrow 2FeS + 4H_2O$

This reaction results in the creation of ferrous sulphide, which turns the media from its original orange colour to black.

Media Regeneration

When the media becomes saturated with sulfide, it is regenerated in-situ and re-used. The media may be regenerated in one of two ways:

1. Batch Regeneration. The scrubber treats the gas until becoming saturated with sulfide, which is indicated by a rise in outlet H_2S concentration. Gas flow to the scrubber is then stopped, and a blower is used to blow ambient air through the scrubber for a period of approximately eight hours. The air reacts with the sulfide to form elemental sulfur and also converts the iron coating on the particles back to its original ferric hydroxide form.

The media regains virtually 100% of its sulfide adsorption capacity. The chemical reaction is as follows:

$2FeS + 3/2\ O_2 \rightarrow 2Fe(OH)_3 + 1/4\ S_8$

In this reaction, oxygen converts the FeS to ferric hydroxide and elemental sulfur that stays attached to the media. Visual observation during regeneration shows the media turning to its original orange color with small sulfur particles attached.

During the initial hour or so of regeneration, the outlet air may contain a small amount of H_2S (perhaps 50 ppm), due to some gas which may be remaining in the interstitial spaces between media particles. After this time, the concentration of H_2S in the outlet gas becomes very low. Overall, less than 0.02% of the H_2S removed by the scrubber is released to atmosphere during the regeneration process. If the small H_2S release during regeneration is unacceptable, a small secondary scrubber can be installed to scrub the regeneration air for that period. A certain amount of heat is generated in the regeneration reaction, but due to the fact that the media substrate is an inert mineral there is no risk of its combustion (unlike some other adsorbent media, which are combustible).

After regeneration, the scrubber is put back into normal service. Typically, up to a dozen regenerations are possible. Due to the large amount of sulfur accumulating within the media bed (the media can adsorb 40% to 50% of its weight in sulfur after this many regenerations), an increase in pressure drop through the scrubber is normal. As the media approaches H_2S saturation, the pressure drop may exceed 14 kPa. Blowers should be sized accordingly.

For safety reasons, the scrubbers must be purged with CO_2 or nitrogen before regeneration and after regeneration (before return to service). This avoids a possible flammable mixture of oxygen (air) and methane, hydrogen, or other explosive components in the gas stream.

2. Continuous Regeneration. Rather than periodically removing a scrubber from service, it is possible to carry out continuous, on-line regeneration, by ensuring a small amount of air is present in the gas stream. This results in both the adsorption and regeneration reactions taking place simultaneously. In many instances, sufficient air may be present naturally in the gas stream, while in others a small amount may be added if necessary.

For high concentrations of hydrogen sulfide in the gas stream, complete regeneration may not occur and therefore, a batch regeneration is preformed.

Care should be taken that a flammable mixture is not formed, based on the relative concentrations of components in a given gas stream.

When treating an air stream with a hydrogen sulfide concentration of 1000 ppm or less, the self-regeneration process will take place and a separate batch regeneration typically will not be required.

Disposal of Spent Media

When replacement of media becomes necessary, the scrubber should first be regenerated and then purged. If the scrubber is a simple odor-control type with a removable cover, this cover may be removed and the media scooped out with a backhoe or manually shovelled out. If the scrubber is of the pressurized container type, it should first be regenerated with air, as described above, then de-pressurized and then the hatch at the top and side of the vessel can be opened and the media removed by means of a vacuum truck. The media remains free-flowing even after being saturated with sulfur, but mechanical prodding may help in the vacuuming process. The spent media passes the US EPA's TCLP test as non-hazardous waste, suitable for landfill disposal. However, environmental agencies should be consulted for procedures in your area. Also, other contaminants in the gas stream may have been adsorbed, so it would be advisable to conduct a TCLP test after the first use of the media.

Options for Biogas Cleaning and Use On-farm

by A. Skerman, G. Collman, J.H. Sohn and L. Pott

Pub. No. 12/056

This project investigated technologies for conditioning biogas for on-farm use, primarily focusing on the removal of hydrogen sulphide. While several existing technologies have been successfully developed and used for removing H_2S in large-scale industrial applications, this project has attempted to identify and demonstrate robust, cost-effective options, suitable for implementation on farms of various sizes, with minimal labour input and limited specialised expertise.

In addition to investigating biogas cleaning (conditioning), this project also involved installing a water heating unit (pictured on the front cover) burning biogas to heat water that is circulated through floor heating pads installed in the farrowing sheds at the QNPH Grantham piggery. This biogas fired heating system has the potential to significantly reduce on-farm energy costs by replacing a significant proportion of the Liquid Petroleum Gas (LPG) previously used for farrowing shed heating.

RIRDC is a partnership between government and industry to invest in R&D for more productive and sustainable rural industries. We invest in new and emerging rural industries, a suite of established rural industries and national rural issues.

Most of the information we produce can be downloaded for free or purchased from our website <www.rirdc.gov.au>.

RIRDC books can also be purchased by phoning 1300 634 313 for a local call fee.

RURAL INDUSTRIES
Research & Development Corporation

Phone: 02 6271 4100

Fax: 02 6271 4199

Bookshop: 1300 634 313

Email: rirdc@rirdc.gov.au

Postal Address: PO Box 4776, Kingston ACT 2604

Street Address: Level 2, 15 National Circuit, Barton ACT 2600

www.rirdc.gov.au