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Techno-Economic Evaluation of EEI Self-Regulating Suspended Biogas Collectors (SSBC) for Abattoirs

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Abstract

This report presents reviews on covering technologies for anaerobic lagoons and vertical reactors and the applicability of the new patented system, "EEI self-regulating suspended biogas collectors (SSBC) for the meat industry. The review has found that there are a limited number of fixed and floating covering systems made up of polymer materials such as HDPE for anaerobic lagoons. No viable modular technologies for covering anaerobic lagoons have been encountered. There exist several challenges for the stable operation of fixed dome systems such as rainwater collection, and uneven stress due to wind and rainfall. The technology for a floating cover is complex however, it addresses a number of issues that are faced by fixed cover systems. It provides access to the lagoon for desludging or mixing without the same level of difficulty present in fixed covers.

In Australia, no vertical anaerobic reactors have been reported for use in abattoirs, except for the reactor located at the Dardanup Butchering Company (DBC) facility in Picton, WA. The uncovered EEI HART reactor installed at DBC has been found to be operating without any odour generation or excess crust formation issues for the past six years. The review of cover materials for vertical reactors in other industries indicates that fixed and floating covers are common for vertical anaerobic reactors. However, the retrofitting of covers for existing open anaerobic reactors is found to be difficult due to high costs as well as risk transfer to clients among other non-technical challenges.

The report evaluates the Self-Regulating Suspended Biogas Collector (EEI-SSBC) system with regards to its suitability for the red meat industry. The evaluation covered the parameters such as material selection, typical costs, operation and maintenance issues and life expectancy.

The suitability of the system is discussed with respect to a number of aspects like managing floating crust, extreme weather conditions, rainwater management, installation and commissioning restrictions. In each case, EEI-SSBC technology was found to be a superior alternative in comparison to conventional gas covering systems. The modular nature of the SSBC system ensures far easier maintenance that does not disrupt power generation downstream.

The report also provides details of various materials used for the construction of the gasholders for SSBC systems for the red meat industry. These include stainless steel, high density polyethylene (HDPE), fibreglass, galvanized iron and ferrocement. Each material is evaluated in terms of its strength, weight, cost of construction, UV resistance and fat oil and

grease (FOG) resistance. HDPE and fibreglass were found to be the cheaper options as compared to stainless steel and galvanized iron.

The two methods of implementing EEI-SSBC are:

(i) Positioning the gas holders on a crisscross platform

(ii) Self-balanced individual floating roof.

The first method is a more robust model because the gasholder movements are tightly restrained. The amount of material and cost of construction is expected to be much less for the second method compared to the first.

An investigation on the effect of the roof dimension of each module on important performance characteristics such as operating gas pressure and submergence of the platform under water level has also been carried out. The analysis was carried out for all the candidate materials and it was found that stainless steel and ferrocement modules would result in very high levels of submergence due to their higher specific gravity.

Presented in this report are the results of a detailed design evaluation of the EEI-SSBC system and its integration into DBC's vertical high-rate anaerobic reactor. The key findings of this evaluation highlight the potential issues associated with the use of the EEI-SSBC with DBC's anaerobic reactor, as well as the technical solutions to these issues. Through this process, the most suitable design applicable to the situation has been selected. The proposed design takes into consideration a number of factors including but not limited to the interaction between the gas holders and the anaerobic reactor wall as well as environmental effects. The SSBC system is to be constructed primarily using fibre-reinforced plastics.

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1 Introduction

The production of energy using methane rich biogas from the anaerobic treatment of wastewater provides an opportunity for sustainable operation of meat processing facilities. By capturing this biogas and using it for the production of power, the environmental footprint of these facilities can be reduced and significant savings in cost can be achieved.

Typically, the collection of biogas is accomplished by covering the anaerobic treatment system, be it a lagoon or a reactor. However, the current technologies available for the capture of biogas at facilities treating meat industry effluent suffer from a number of issues.

The purpose of this project is to identify the disadvantages present in current covering technologies and present a technology which mitigates these issues and is suitable for use for meat industry effluent. This report presents the results of EEI's research in the field of biogas collection technologies and their implementation at abattoirs. The key objectives of this project are listed below:

1. Review of the existing gas collection technologies and cover materials for anaerobic lagoons/reactors for abattoir effluent including materials, typical costs, O&M issues, life expectancy

2. Review of the existing technologies for retrofitting biogas collectors for uncovered anaerobic lagoons and reactors

3. Evaluation of the EEI-SSBC technology for anaerobic systems treating abattoir effluent including suitability, selection of construction materials, typical costs, O&M issues, life expectancy

4. Identification of a suitable design of EEI-SSBC technology for Dardanup Butchering Company's anaerobic reactor for retrofitting including modular design concepts, interconnection of individual gas collectors, material of construction, prevention of gas leakage

2 Literature Review

2.1 Abattoir Effluent Treatment – An Introduction

Abattoir or meat processing industry effluent is considered to be of high strength and requires a series of treatments before the water can be discharged to the environment or recycled. These include primary treatment, secondary treatment and advanced treatment. The treated effluent is partially reused for truck washing or floor washing in some cases, and the rest is disposed of through land applications such as irrigation. In cases where land application is not possible, the partially treated effluent is discharged to the municipal sewers. An overview of each stage of treatment is provided in the following sections.

Primary Treatment

Primary treatment, sometimes known as pre-treatment or screening is normally a physical or chemically aided physical process. This process is applied to remove settleable and floatable material. This is the first of the "end of pipe" processes and does not rely on any waste minimisation or recovery systems used in the plant itself (MIRINZ 1991). Effective primary treatment is very important as inadequate treatment at this stage would allow large quantities of solids to enter the secondary treatment system. Subsequent bacterial breakdown of the solids liberates large quantities of nitrogen (as ammonium ions) and phosphate into the liquid phase, which adversely affects the efficiency of the secondary treatment system and/or the cost of operating the secondary treatment system. For example, paunch solids, if not removed at the primary treatment, can cause a floating mat or crust in the downstream anaerobic step. For open (uncovered) anaerobic lagoons, this crust is required as a method to prevent odour generation (by way of oxidising odorous gases such as hydrogen sulphide). For covered anaerobic lagoons (CAL) or reactors, the crust formation can cause severe damage to the operation of the system including the reduction of available gas storage area and the damage of the cover materials.

Secondary Treatment

Secondary treatment of meat processing effluent is the next step after primary treatment. In small abattoirs they do not have expensive primary treatment systems such as DAF or filtration systems. They generally have coarse solid separation systems such as screens, and wastewater is directly discharged to the secondary treatment system, which normally is an anaerobic pond followed by aerobic or aerated ponds.

2.1.1 Anaerobic Treatment

The anaerobic treatment process is generally the first phase of the secondary treatment of abattoir effluent. This is mainly because of the high BOD of abattoir effluent, which if removed aerobically would require substantial energy costs in addition to costs related to management of resulting bio-solids from the aeration process. Also, the temperature of the effluent from meat processing plants is about 40°C, which is advantageous for increased BOD reduction. The treatment system is simple to construct and operate, and when operating correctly, commonly achieves 80 to 90% reduction in both BOD and Suspended Solids.

Traditionally, the anaerobic technologies used for abattoir effluent treatment in Australia are either uncovered/open anaerobic lagoons or ponds. The dissolved fat in abattoir effluent that passes through the primary treatment system facilitates the formation of a natural crust and insulation layer on the surface of the pond. This crust also hosts multiple species of beneficial aerobic/ facultative bacteria that oxidise hydrogen sulphide and other odorous gases, as well as methane, which in fact reduces the carbon footprint.

Recently, due to odour complaints from neighbourhood residential or commercial communities – mostly because of developments near abattoirs, there is an increasing demand for covering anaerobic lagoons. These increasing demands are also driven by the capture of biogas for energy production in order to partly or fully meet the total energy requirement of abattoirs. Due to stringent regulations by environmental protection agencies in terms of minimum depth from the base of the ponds to the site groundwater level (for example 2 m in the case of Western Australia), as well as the large land area required for anaerobic lagoons, many abattoirs are considering advanced anaerobic reactor technologies.

2.1.2 Aerobic Treatment

Aerobic treatment is the downstream process following anaerobic processing of abattoir effluent. Aerobic treatment often consists of the removal of residual BOD, nitrogen and phosphorus to the levels required by the regulators.

The traditional aerobic treatment method uses an aerobic pond followed by a maturation pond. There is relatively little nitrogen and phosphorus removal in abattoir effluent if a natural pond treatment system is used. However, aerated systems with different types of aerators such as surface aerators either in a pond or tank can provide enhanced pollutant removal while having a smaller footprint. The aerated pond or a tank is essentially an activated sludge plant if no growth media or moving bed is placed in the water column. There are a number of variants of activated sludge processes that are employed including the extended aeration systems with a sludge separation facility, sequencing batch reactors (SBR) and membrane bioreactors (MBR). Selection of these processes is based on the mode of operation, reclamation of treated water and sludge residence time. If a growth media is attached, the operation will be different to an activated sludge system. Depending on the operation, it will be a trickling filter where the media is stationary or a fluidized bed such as a moving bed bio reactor (MBBR) where the media is in a dynamic state.

The activated sludge or attached growth systems are capable of removing nitrogen to over 95% to 99%, biologically. Some systems can remove phosphorus biologically (25 to 99%) but chemical phosphorus removal is the common method for abattoir effluent.

The ANRUP (advanced nutrient removal unit process) system developed by Environmental Engineers International Pty Ltd and operated at Dardanup Butchering Company provides 90% removal of nitrogen using the Anammox process, with about 40% of the electricity consumption of conventional technologies. It can also achieve about 50 to 65% of total P reduction biologically.

2.2 Biogas Collection Technologies in Abattoirs

In Australia, the common method of anaerobic wastewater treatment for abattoirs is anaerobic lagoons. Covered anaerobic lagoons – constructed either by retrofitting a cover or building a new covered lagoon – is the current trend in the Australian meat process industry for biogas collection.

Traditionally, anaerobic lagoons have been constructed as open dams, where the biogas generated is released to the atmosphere through a floating crust. In the past decade, Australian abattoirs started building covered anaerobic lagoons mostly to recover biogas for energy production and to contain odour generated from lagoons. Apart from the EEI HART system installed at DBC, there have been no reported vertical anaerobic reactors installed in the Australian red meat processing industry, as confirmed by an extensive search of MLA and AMPC resources and other reports in the public domain. The following section describes various biogas collection technologies and cover materials for covered anaerobic lagoons (CAL) both in Australia and overseas.

2.2.1 Covered Anaerobic Lagoons

Covered anaerobic lagoons (CALs) are modified anaerobic lagoons/ponds whereby the exposed surface of the lagoons is covered with a geomembrane to capture biogas and odour causing gases such as hydrogen sulphide generated from the lagoons. Although CALs possess many advantages, they still have some disadvantages. One of them is the need to provide maintenance to the geomembrane cover. Due to the extreme environmental conditions in Australia, this disadvantage becomes an important issue that needs to be addressed for sustainable operation of CALs.

There exists extensive documentation regarding the design and operation of CALs. However, detailed research regarding the covering and biogas capture technology is hardly available. From the limited research available, most findings agree on several key points regarding the limitations related to the currently available covering technology. The limitations of the current covering technologies include (Laginestra & Allan (2014), R. Kurup, 2015):

- Stormwater/rainfall ponding on the lagoon cover
- Effects of wind, other natural disturbances and internal stresses
- Accumulation of fat, oil and grease underneath the cover, reducing the gas storage area
- Difficulty in desludging the lagoons and build-up of excessive sludge in the lagoon limiting HRT
- Installation, maintenance, repair and deterioration

- Prone to damage by tears or external forces, and thus the need to replace covers periodically
- Lack of access to internals of the lagoon, for example to desludge or remove excess crust

2.2.2 Fixed Covers for Anaerobic Lagoons / Ponds

Fixed covers are typically made out of a thicker geomembrane in comparison to other covering technologies. Due to the rigidity of the design, this type of cover is generally used in systems where variation of effluent level is minimal. Material choice for this design is not restricted as high flexibility is not required. The fixed cover system is often constructed sequentially and launched over a filled pond. The design may restrict movement of the cover material by placing stiffener strips in the cover. This prevents movement from drag effects due to currents in the effluent below the cover and from wind above the cover.

Many of these cover designs involve entrenching and burying the edges of the cover in the banks, making it very difficult to remove covers and subsequently perform pond maintenance such as de-sludging and crust removal (MLA, 2012).

To improve gas collection from the pond a series of floats or void formers may be included below the cover system to allow for space above the effluent surface (MLA, 2009). The biogas accumulates in this space and is removed either by internal pressure (positive pressure) inside the cover or by application of low suction pressure using root blowers (negative pressure covers). The fixed cover system will have a variable internal pressure, as the volume is fixed, and if the generated gas is not collected, then the pressure in the gas storage area of the lagoon will increase, releasing more fermenting liquid to the next pond. If a negative pressure is to be maintained, it is important to ensure the correct pressure.

The stormwater collection systems for fixed covers are designed to shed runoff to designated low points on the cover (sump areas). The collected stormwater is subsequently removed by pumping. It is generally not practical to remove all runoff from the cover and some runoff is removed by evaporation from the cover surface.

There are several advantages of fixed covers when compared with other covering technologies. These include:

- Wider variety of material choice
- Lower capital expenditure when compared with floating cover

- More resilient to uplifting due to wind

Despite having some advantages, fixed cover technology also has several major disadvantages:

- Difficulty performing pond maintenance, such as desludging or scum removal, due to lack of access to the inside of covered lagoons
- Due to the stiffness and the size of the cover, localised stresses can occur within some parts of the cover, causing damage which will lead to rupture or structural failure
- Excess floating crust on top of the liquid column can reduce the volume of available gas storage space and further increase the internal pressure, potentially causing rupture or damage to the cover material
- Excess crust can potentially disrupt the operation of CAL by blocking effluent and gas extraction pipes
- Likely chance of gas leakage through the perimeter trench when the internal pressure is high.

Figure 1: A typical fixed covered anaerobic lagoon with captured biogas

Figure 2: Anaerobic lagoon with fixed HDPE cover with details of gas collection pipe

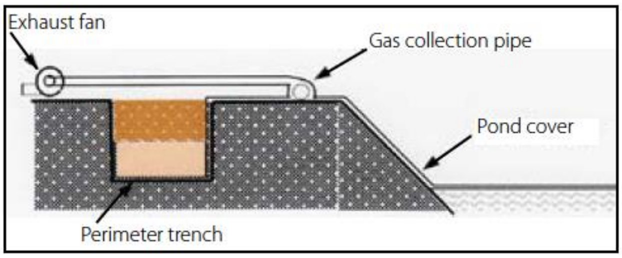

Figure 3: Construction of fixed cover for CAL

2.2.3 Floating Covers for Anaerobic Lagoons

Unlike the fixed cover, floating covers are installed over the surface of the lagoon and will rise and fall following the water level. To accommodate such movement, the covering material needs to have some degree of flexibility. In some cases, additional flexible restraints are required to maintain the desired shape of the cover, such as the one installed at the Churchill abattoir. Floating covers use buoyancy to support the weight of the cover. The cover material is extended to the sides to prevent leakage of gas from the holding area. Normally, the pressure is relatively low unless it is designed for a certain pressure. If the biogas generated is discharged without the assistance of a pump, then the internal pressure will be constant and the cover will rise above the water level to a height whereby any further increase in gas quantity will result in release to the atmosphere through the sides.

In the case of the cover built for the Churchill abattoir, a raft using 100 mm μPVC pipes in a truss arrangement was fabricated based on the design shown in

Figure 4 and

Figure *5*.

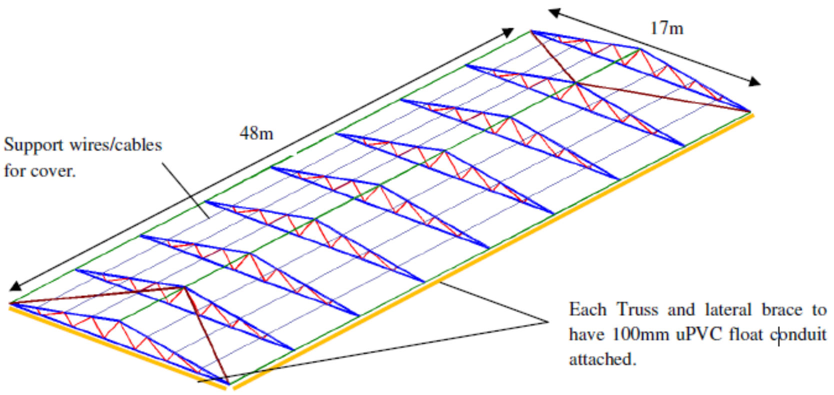

Figure 4: Floating Cover structure with truss and float – Churchill abattoir (MLA, 2012)

Figure 5: Actual design of floating gas cover raft for CAL for Churchill abattoir (MLA 2012)

Following the construction of the raft, the cover to accompany the raft was initially produced from a spray on product - Liquid Rubber™, applied to a commercially available geo-textile membrane. They considered that with the use of Liquid Rubber™, they had the advantage of being able to fix small leaks by patching with further applications of Liquid Rubber™. However, when applied to a small-scale test raft, the rubber cover produced significant leakage, failed to capture gas, and thus the material was subsequently abandoned. Ultimately, the Churchill abattoir used HDPE as the cover material as shown in

Figure 6: Positioning of the floating cover to the anaerobic lagoon.

. The raft was designed to keep the HDPE mat relatively out of contact with the FOG to prevent any reactions with the HDPE cover as can be seen in

Figure 7. It is assumed that the cover had a water seal to prevent the escape of biogas through its sides as there was no information provided on the water seal in their report.

Figure 6: Positioning of the floating cover to the anaerobic lagoon.

Figure 7: Installed cover on first pond, inflated with captured biogas.

The advantages of floating covers when compared with fixed covers can be summarised as:

- Easier access for desludging, as cover can be peeled back and reinstalled
- Easier transportation of material as flexible material can be rolled and assembled onsite
- Can accommodate changes in water level
- Can handle localised stresses better than fixed covers
- Floating scum can be removed hydraulically
- The gas outlet can be positioned in such a way that it would be unlikely to be blocked by floating crust
- Opportunity for leakage of biogas through the sides is less unless the side water seal is lower than the pressure inside the cover
- Retrofitting is easier with a floating cover than a fixed cover.

The disadvantages of floating covers when compared with fixed covers include:

- Higher capital expenditure
- More complex structure, leading to difficulty in design and installation when applied to large ponds

- More vulnerable to uplift due to wind
- More vulnerable to rainfall ponding
- Limited choice of material. The material that supports floating cover are usually more prone to UV degradation
- There will be exposed areas of lagoon with no cover, though biogas lost due to this will not be significant, access to the cover for repairs, maintenance, crust formation and vegetation growth will be a problem

2.2.4 Modular Covers for Anaerobic Lagoons

Modular covers have not been explored extensively for anaerobic lagoons in Australia or indeed worldwide, due to the complexity of the engineering design. There is only one MLA report which has mentioned a modular cover design (MLA, 2009). It appears that this design is a modified system used for the prevention of evaporation in freshwater dams in arid regions as shown in Figure 8. The dynamics of a cover for evaporative water loss is different to that of an anaerobic cover for capturing biogas, as the generation of biogas can raise the cover and topple it if not properly designed. Lewers (2010) undertook a review of modular covers for anaerobic lagoons. A detailed assessment of the designs indicates that a) the overall cost can be very high b) potential for leakages is high and c) degradation of the parts of the cover in FOG and lagoon environments can be substantial. There has been no reported installation of a modular cover for capturing biogas in lagoons in Australia.

Given the large size of anaerobic lagoons, it is recommended that suitable designs of modular covers be developed. It is very valuable for the meat processing industry considering the potential benefits as explained below.
The benefits of modular covers when compared with fixed and floating covers are:

- Easy maintenance for cover and ponds as modules can be detached from the grid to provide access, including desludging and scum removal
- Flexibility in installation as it can be installed on an irregular shaped pond
- Easy to repair, as repair can be done on a modular basis
- Reduce the internal stresses from wind, which prolongs the lifespan of the cover
- Potentially lower capital costs
- Installation of the cover can be done in phases.

To make modular covers commercially viable, it needs to eliminate most of the disadvantages associated with both floating and fixed covers, while maintaining or possibly lowering the cost of installing the existing technology.

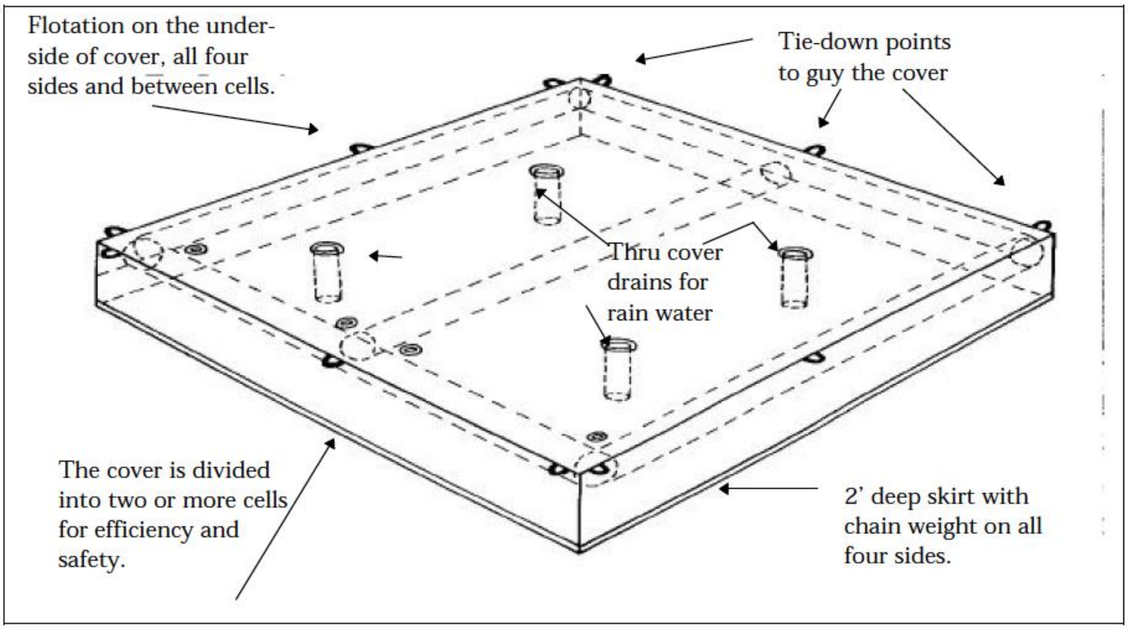

Figure 8: Modular cover used for evaporation loss in dams (US EPA, 1997)

2.3 Biogas Collection Technologies for Vertical Anaerobic Reactors

Due to limitations in available land area, operational ease such as sludge removal and stringent regulations with respect to the minimum distance required between the base of anaerobic lagoons and groundwater level, there is a new outlook for vertical anaerobic reactors in the meat processing industry in Australia. The Dardanup Butchering Company (DBC) has installed such a system - the high rate anaerobic reactor technology (HART), developed by Environmental Engineers International Pty Ltd in 2010. The operation of the uncovered HART system since commissioning has proven that over 95% of BOD is removed by the system, with no odour issues or other problems. As the impacts (particularly on potential formation of thicker crust) of the efficiency of primary treatment including the removal of fat, oil and grease (FOG) on the vertical anaerobic system was unknown, it was decided that the reactor be built without a cover. After five years of operation of the EEI HART system, DBC has yet to find any evidence of crust formation on the system’s water surface. At the same time, odour production is a non-issue for the HART system.

Figure 9: The EEI- HART system in operation at DBC

2.4 Vertical Anaerobic Reactor Tank Covering Technology

2.4.1 Fixed Covers

Fixed covers for vertical anaerobic reactors may be constructed using several methods. The materials used for construction can be concrete or ferrocement – self spanning or column supported, and of various thicknesses. These types of covers are not very common for tall tanks, though conventional biogas plants used in India and China have these types of covers, where access is available through the inlet or outlet ports.

However, in order for the repair of any leakage, the reactor has to be completely emptied and any remaining gas has to be pumped out. In addition, repair personnel have to wear gas masks. Many untrained persons attempting to undertake repairs inside of such biogas plants are met with hazardous conditions, suffering from loss of consciousness or in some cases even death.

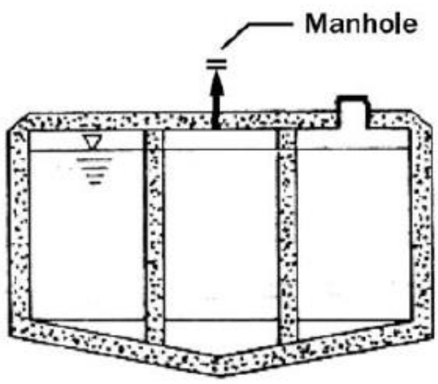

Figure 10: Flat fixed cover – made in concrete or ferrocement

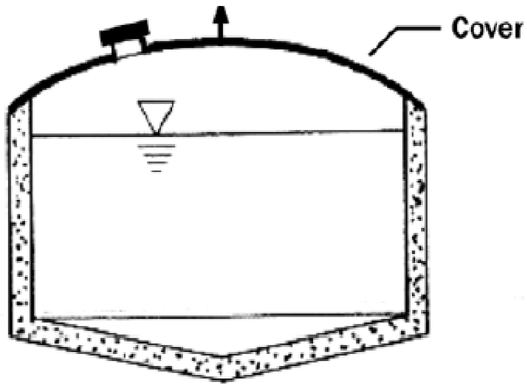

Figure 11: Domed fixed cover – made in concrete or ferrocement

The egg shaped anaerobic covers have been used for anaerobic sludge digesters in Australia and overseas. These covers are made with concrete and are an integral part of the digester walls. It may not be a suitable design for anaerobic reactors treating abattoir effluent due to the opportunity for formation of a thick crust. No studies have been reported on the use of such type of anaerobic reactors for abattoirs.

Gas covers for vertical anaerobic reactors have been constructed with various types of steel welded to the upper chord of a truss or to an arch-rib supporting framework. The supporting framework is connected to the top of the wall by a sliding arrangement that allows the cover to expand or contract in response to changes in temperature. Walker Process Equipment, a US based company supplies this type of cover for anaerobic reactors, but they are mostly used for sewage sludge digestion or non-crust forming wastewater (Walker, 2015).

Figure 12: A typical arched beam fixed cover for reactors, made in steel

Walker fixed covers are anchored to the top of the reactor tank, and normally sludge/wastewater levels are static or constant. The depth of the rim plate will act as freeboard alongside the tank operating pressure and an appropriate seal depth to contain the gas. A fixed cover has only one steel membrane over its structural framework. At the top of the gas cover, a gas outlet is provided, so biogas can be withdrawn without also removing entrained liquid, scum or foam. There are sampling wells, which have quick-opening hatches, with seal pipes extending below liquid, so that samples can be withdrawn without losing gas. The tank cover has a pressure relief and vacuum-breaker valve, mounted atop the gas dome for the purpose of relieving gas upon over-pressurization, and allowing atmospheric air to enter if a vacuum exists when the cover sits on corbels. This valve is a safety device, protecting the structure. Although this type of tank cover is not very costly, the disadvantages are that there is limited biogas storage capacity, the biogas will have low pressure and an external pump is required. There is no scum/crust suppression system. The application of such covers for anaerobic reactors treating abattoir effluent is to be evaluated thoroughly.

There are other tank covers, which are normally built along with the fabrication of the tanks (not necessarily suitable for retrofitting) such as the tanks and covers provided by Tank Connection, CST and similar suppliers. Roof panels can be designed with Vitrium glass-fused-to-steel coating, OptiBond Epoxy Coating System, stainless steel (Figure 13) or even a flexible membrane based cover (

Figure 15). During our meeting with a CST representative, it has been mentioned that geodesic dome types made in aluminium are very light weight, but there exists potential for gas leakage and hence they are currently not promoted (Figure 14). We have not yet come across any literature on the use of flexible membrane roof covers (as shown in

Figure 15) for vertical anaerobic reactors.

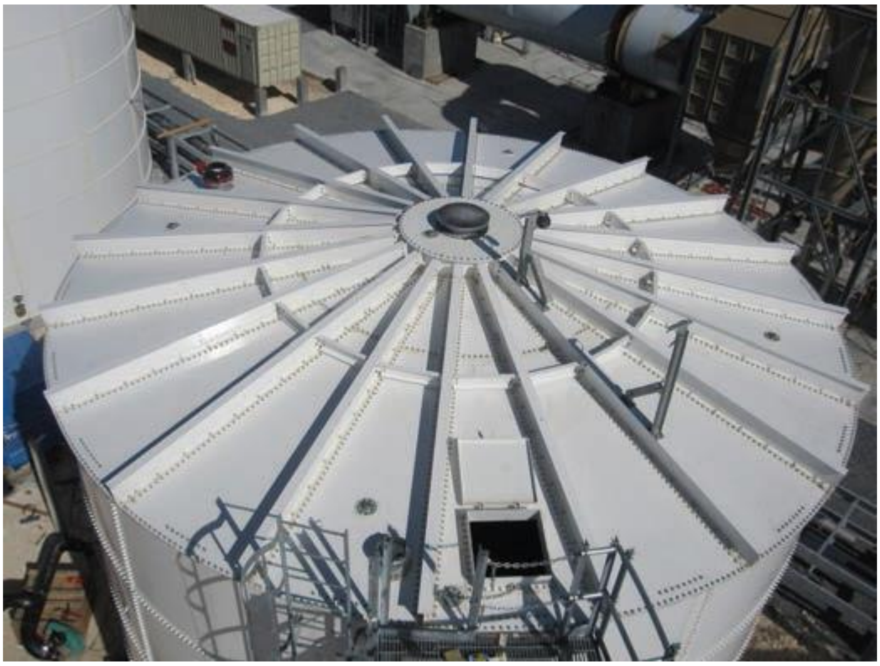

Figure 13: Steel covers for anaerobic tanks with bolted steel design

Figure 14: All aluminium geodesic anaerobic cover design

Figure 15: A membrane based fixed gas cover

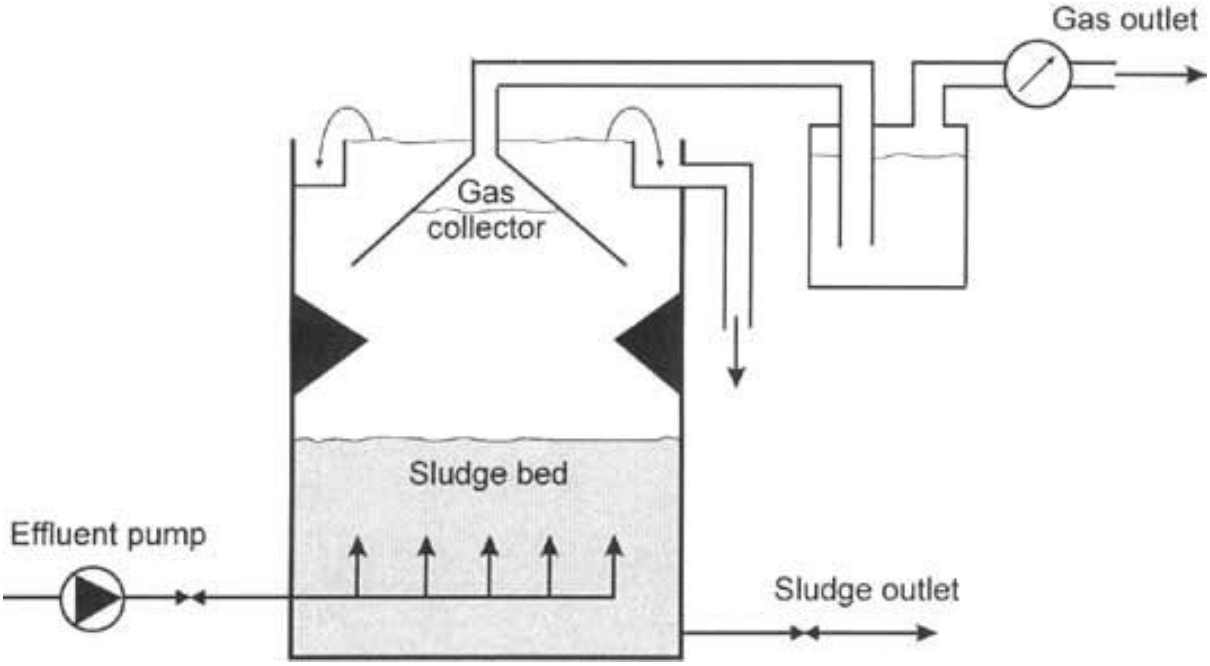

Figure 16: A typical UASB reactor

The up-flow anaerobic sludge blanket reactors (Figure 16) have been a breakthrough in the area of anaerobic digestion technology as they only require less than 10 hrs residence time while generally removing over 90% COD. It is used extensively for high strength wastewaters with low suspended solids, low FOG, and high alkalinity. The gas collection system is an integral part of the reactor, which also acts as a gas-liquid separator. It is immersed in the reactor below the top liquid level, and the generated gas is stored in an external storage facility until ready to be utilised. Given the high TSS and FOG contents and opportunity for crust formation, UASB reactor technology has not yet been reported to be used successfully for the meat processing industry.

One of the major disadvantages of fixed covers is their inability to tolerate changes in liquid levels inside of the reactor. Therefore, it is essential to maintain an equal volume of the liquid entering and exiting in order to maintain the water level. If influent exceeds effluent, it will pressurise the reactor which could lead to failure in the mounting structures. If effluent exceeds influent, it will create a vacuum that can damage the cover. Hence, it is a common practice to install a pressure relief system to reduce this risk. Another disadvantage of this type of cover is its tendency to develop gas leaks at the interface of the cover and wall. From an operational point of view, it is difficult to perform maintenance on the reactor as the only access to the reactor is through the manhole. In addition, the supporting framework inside the reactor is subject to corrosion, especially when H_2S is expected in the gas. Therefore, it is recommended that sufficient corrosion prevention is implemented and recoating of the cover is carried out every 5 – 10 years, depending on the environmental conditions.

2.4.2 Floating Covers

Floating covers are similar to the fixed covers, but instead of fixing the cover to the wall of the reactor, it has a system of roller bearings and rails to allow vertical and lateral movement. Due to the different mounting system, the cover will float directly on the liquid surface and will move according to the water level. The typical design of a floating cover will allow vertical motion of 1.5 to 3 m. Due to its ability to move, the issue of pressurisation due to the difference between input and output of liquid will not occur. Since the cover is floating on the surface of the water, it will also supress scum production.

Figure 17: Details of a floating cover for anaerobic reactors

Figure 18: A floating cover is being positioned on a vertical anaerobic reactor

Despite having some benefits, floating covers also have several disadvantages. The main disadvantage of a floating cover is the complexity of the supporting structures which allows the vertical and lateral movement. This means that the cover has a higher capital and operating cost than fixed covers. Aside from that, these covers are more prone to corrosion, thus requiring better corrosion prevention measures. Furthermore, due to the high grease and oil content typical of the effluent from meat industry waste, it is required that material's that are in contact with the liquid have high chemical resistance.

The other disadvantages of floating covers are their high maintenance requirements. A floating cover needs to be inspected periodically to ensure that it is level and is able to move freely. As the cover is supported by gas, it is the most unstable cover relative to the other types of covering technologies. Similar to other types of cover, it is difficult to perform maintenance on the reactor and cover due to limited access.

2.4.3 Double Membrane Covers

Double membrane covers utilise membranes to capture gas produced from a reactor. These covers consist of two membranes (inner and outer membrane) that are attached to the wall of the reactor, similar to a fixed cover. The function of the inner membrane is to capture the gas and transfer it to pipes for distribution. The inner membrane also acts as a gas storage facility and will inflate and deflate in response to the volume of gas stored in the cover. The outer membrane's function is to provide pressure to the inner membrane, thus increasing the pressure of the gas to the suitable level. This is accomplished by having a blower system attached to the outer membrane so that air can be blown to inflate the outer membrane and push the inner membrane. The outer membrane is also supported with dome structure framework to prevent collapse upon deflated.

There are several advantages associated with the membrane covers. First, this cover provides a pressurised gas storage system and hence high pressure gas storage and gas compressors are not required. If the expected gas storage requirement is high, this cover will become an economical solution. Second, if the reactor is subjected to foaming, the gas storage section of the cover will act as a buffer so that no foam will enter the gas piping. Finally, the inner membrane also acts as corrosion prevention as it will cover the supporting structures that are located between the inner and the outer membrane.

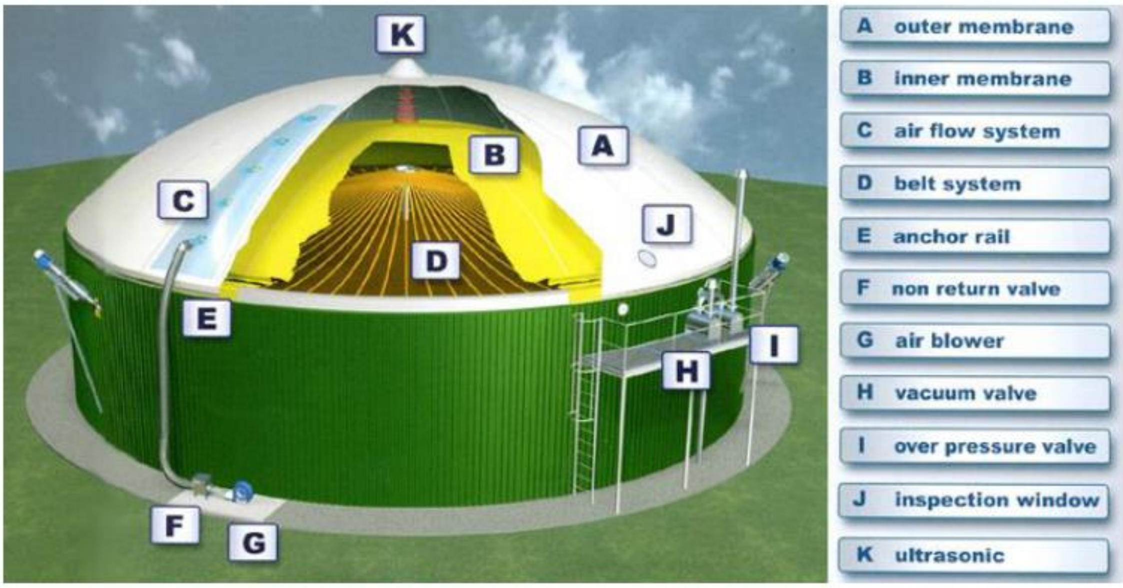

Figure 19: A diagram a double membrane gas cover for anaerobic reactors

Figure 20: An operating anaerobic reactor with double membrane gas cover

The main disadvantage of this cover is the lack of access to the cover and the reactor, which makes it difficult for operators to perform maintenance. The cover may be designed for maximum wind force, however, damage due to extreme weather events such as storms and high wind may be possible. Localised damages to the outer cover may be fixed without decommissioning the anaerobic reactor, but if any access to the inside of the reactor is required, the cover will have to be replaced.

2.4.4 Gas-Holder Covers

Gas-holder covers are similar to floating covers, but instead of floating on the liquid, they float on top of the gas produced from the reactor. This type of cover often has a skirt that goes below the liquid surface to capture most of the gas. The advantage of this cover in comparison to floating covers is the availability of space beneath the cover for gas storage. Additionally, this type of cover is cheaper than floating covers, though they are more expensive than fixed covers, which sometimes makes them the best option for covering a reactor.

The major disadvantage of gas-holder covers are high maintenance requirements. The cover needs to be inspected periodically to ensure that it is level and able to move freely. As the cover is supported by gas, it is the most unstable cover relative to the other types of covering technologies. Similar to other types of cover, it is difficult to perform maintenance on the reactor and cover due to the limited access.

2.5 Existing Technologies for Retrofitting Biogas Collectors for Uncovered Anaerobic Lagoons and Reactors

2.5.1 Lagoons Covering Technologies

The biogas covering technologies for anaerobic lagoons discussed in the previous sections will be suitable for retrofitting to existing uncovered lagoons. Fixed and floating covers are particularly suitable for retrofitting to uncovered lagoons. Due to easy access to the foundation and mounting points (located at ground level), retrofitting covers to an uncovered anaerobic pond is not technologically challenging. For fixed covers installed on an uncovered anaerobic pond, trenches should be constructed along the perimeter of the pond to act as the mounting point. Geomembranes can then be attached to the mounting mechanisms. The only limitation of installing fixed covers to an uncovered anaerobic lagoon is the availability of space along the perimeter of the pond and the suitability of the soil for supporting the mounting mechanism. As with floating covers, similar civil work needs to be done to install the mounting mechanism for the cover.

However, this easy installation can only be achieved if the pond is rectangular in shape. If the shape of the pond is not rectangular, installation is more difficult and sometimes impossible. Despite the fact that retrofitting a cover to an uncovered anaerobic lagoon is relatively easy, both types of cover still have the associated disadvantages due to design flaws. One of the key disadvantages is the difficulty in performing maintenance on the cover and ponds due to the limited access. Aside from that, work that needs to be done to the pond, such as desludging or scum removal is difficult due to the difficulty of mobilising the cover. Another disadvantage is the inflexibility of modification or addition of equipment to the pond. For example, if the installation of a mixer in the pond is required, the installation process will be difficult and in some cases is not even possible. Therefore, due to the inflexibility of modification and operation and maintenance problems, a better solution for covering uncovered anaerobic lagoons is required.

2.6 Reactor Covering Technologies

Retrofitting a cover to an uncovered anaerobic reactor is more technologically challenging than that case of anaerobic lagoons. This is due to several factors including harder access to the installation point (i.e. reactors are usually 6m tall) and differences in the manufacturer designs of the reactor. These differences in reactor design usually discourage firms in retrofitting a cover for a reactor designed by a different firm due to the risks involved. Even if the firm is willing to install the cover, the cost of installation would be high due to the high risks involved. This problem will apply to all of the currently available types of cover. In addition, even if the retrofitting of covers is financially feasible, the problems associated with design flaws of the covers will still exist. One of the problems is the difficulty in operation and maintenance of the reactor and cover due to the limited access and the immobility of the structures. In addition, the current covering technologies for reactor does not allow installation of additional equipment, hence future upgrades of the reactor (for example installation of mixers) requires a new cover.

2.7 Types of Materials

For covered anaerobic lagoons, the typical material for construction are geomembranes (polymers). For vertical reactors, a variety of materials including geomembranes are used.

There are a number of types of geomembrane that are currently used as the material of choice for lagoon covers. An MLA (2009) study provides a detailed review of various types of cover materials used for covered anaerobic lagoons and their vulnerability. A summary of the most commonly used materials is presented here. These materials include High Density Polyethylene (HDPE), Low Linear Density Polyethylene (LLDPE), Flexible Polypropylene (R-fPP), Ethylene Interpolymer Alloy (EIA), and Chlorosuphonated Polyethylene (CSPE).

2.7.1 SSBC Technology

The self-regulating suspended biogas collector (SSBC) technology, overcomes the drawbacks of the current technologies of biogas covers/collectors of anaerobic digesters. The SSBCs are constructed in a modular fashion. Each module can float independently, be retrofitted to an existing reactor/lagoon, and can provide variable gas pressure or storage volume. Furthermore, any damage to one of the modules can be fixed without shutting the digester down. The problems such as excessive crust formation or servicing anaerobic digester mixers can also be easily managed with SSBC technology. The system can manage extreme wind, cyclone and rainfall events with no or minimal damage which can be rectified without shutting down the digester in contrast to conventional systems.

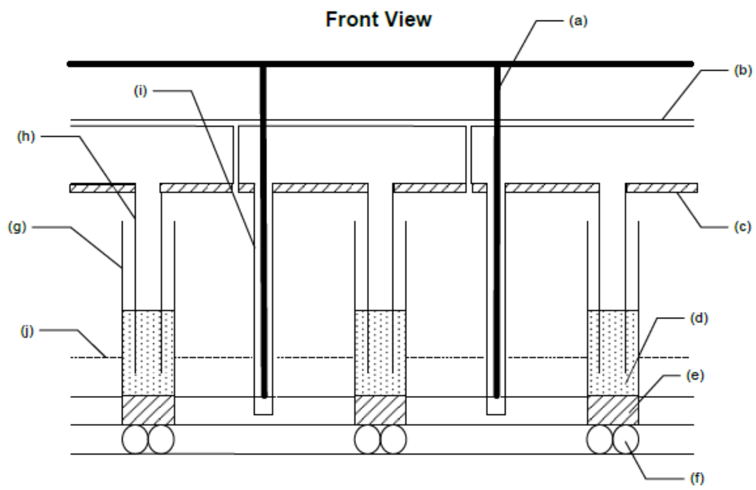

Figure 21: **Cross-section of the SSBC System**

The components of the SSBC system are as follows: (a) Support weight, (b) Gas outlet, (c) Polystyrene foam support, (d) Sealing water, (e) Polystyrene foam slab, (f) Air filled PVC pipe, (g) Channel, (h) Gas holder, (i) Slot for support weight, (j) Wastewater level

The Self-regulating Suspended Biogas Collector (SSBC), is a viable and cost effective alternative which resolves the limitations posed by the existing technologies for biogas capture from anaerobic digesters including covered anaerobic lagoons. The SSBC consists of a number of smaller floating roof collectors instead of a single large dome to cover anaerobic reactor/lagoon including retrofitting.

2.8 Typical Costs

Typical costs for converting an open anaerobic lagoon to a covered anaerobic lagoon is in the range of $500,00 to $2 million, depending on the size of the lagoon, location, access to site and site conditions such as soil, construction of the lagoon etc. For example, when EEI contacted a price for covering the anaerobic lagoon of Harvey Beef in 2002, the quotes received were ranging from $150,000 to $450, 000. If a new CAL is being constructed, the overall cost may be reduced as the mobilisation cost for the construction of the lagoon will be shared with that of the cover.

In the case of anaerobic reactors, depending of the size, the cost may vary between $750,000 to $2 million for a complete vertical reactor, including the gas cover. It is only very indicative as the cost depends on several parameters, such as earthquake region, height, diameter, wind force etc. When EEI sought for a price to retrofit an anaerobic cover for the existing vertical anaerobic reactor, the quotes ranged from $1.5 million to $2 million, essentially because of the risks involved in covering a tank designed and built by a third party. It can be assumed that the retrofitting costs of anaerobic covers for vertical reactors may be much higher than building an integrated reactor with a cover to capture the biogas produced.

2.9 Suitability of SSBC Technology

The suitability of SSBC technology for anaerobic systems treating abattoir effluent is discussed in this section. The important criteria set out in a previous study by MLA for the selection of covers for anaerobic lagoons which can also be extended to tall reactors are the following: rainwater management, rise and fall of the pond level, thermal expansion and contraction effects, avoiding blocking of gas collection paths, wind resistance, installation restrictions, ease of in-service repair and cost (MLA, 2009). These and other major parameters including floating crust, extreme weather events, O&M issues, and corrosion potential are discussed in this section.

2.9.1 Floating Crust

The characteristics of wastewater from abattoirs are different to typical sewage and other high strength wastewater such as from the brewery or sugar industry due to high fat, oil and grease (FOG) content. The FOG in abattoir effluent ranges from 700 to 4000 mg/L. This high level of FOG causes crust formation in the anaerobic system in most cases.

Crust formation is important to control odour generation from uncovered anaerobic lagoons. When the anaerobic systems are covered, the floating crust can cause a number of problems such as reduced storage volume for biogas, potential blockage of gas outlets and safety valves and damage of gas covers due to potential chemical reaction with FOG. Conventional gas covering systems such as covered anaerobic lagoons and fixed double membrane covers for reactors all suffer major problems if excess crust formation occurs. The design of such covers does not allow removal of the excess crust without shutting down the anaerobic system and removing the cover.

The SSBC technology has the capability to manage problems due to floating crust. If there is excess crust, the individual gas covers can be temporarily detached and the excess crust can be removed using a vacuum truck, without shutting down the operation of the system. The cost of managing the excess crust while the SSBC technology is employed will be a fraction of the cost of conventional technologies such as covered anaerobic lagoons (CAL) or double membrane systems. The SSBC technology allows regular observation of the thickness of crust, and if required the crust thickness can be reduced either by using a physical mixer or a water sprayer system. As individual gas covers can be isolated, the biogas stored in the rest of the gas covers will not be lost, hence energy loss and greenhouse emission can also be reduced.

2.9.2 Extreme weather events

The SSBC has been designed with consideration to extreme weather events such as cyclones, storms, rainfall and temperature. The current technology of covered anaerobic lagoons (CAL) and the double membrane system of anaerobic reactors face challenges in dealing with such weather extremes. The modular gas holders of the SSBC can allow stormwater through the reactor/lagoon, rather than holding it on the cover surface. Similarly, wind forces can be distributed to all the gas holders, while shock absorbers can dissipate the resultant force due to wind effectively. In tall reactors installed at regions of extreme weather events such as the northern Australia, an auxiliary software system provides additional safety such as lowering the height of the gas holders. The water seal is designed to be at a constant level so that the risks that arise as a result of evaporation due to elevated ambient temperature and wind can be managed.

2.9.3 Operation and Maintenance (O&M) Issues

Conventional gas covers for both anaerobic lagoon and anaerobic reactors have a major limitation – access to the interior of the anaerobic system. The upflow anaerobic sludge blanket (UASB) reactors are an exception to this. However, due to high crust formation and FOG and TSS content of the abattoir effluent, not many UASB systems have been installed for abattoirs.

The SSBC technology has been designed to overcome the O&M issues of the conventional anaerobic systems of abattoirs. The modular design of the gas covers provides access to the interiors of the anaerobic systems for removal of both sludge and excess crust, installation/replacement of mixers, heat exchangers or retrofitting any equipment such as sensors. Each gas holder has its own water seal so that temporary removal of any gas holder will not impact the operation of the anaerobic system and downstream operations such as electricity and heat generation. The operation and maintenance of the covers are also easily manageable, as any damaged gas cover can be removed for repair or replacement.

2.9.4 Corrosion potential

Anaerobic covers and fittings made up of metals such as mild steel or even galvanised or stainless steel can be subjected to corrosion. Frequent wetting and drying of exposed surfaces of anaerobic covers made up of steel can cause corrosion. Similarly, the underside of the steel covers of anaerobic digesters are vulnerable to corrosion caused by the presence of H_2S in the biogas. In general, the areas affected by corrosion include surfaces that are not submerged, such as undersides of covers, tank walls above liquid surface, and exterior surface of covers, which are exposed to the atmosphere. The SSBC system can use a variety of materials for construction depending up on a number of parameters. If the biogas consists of a high concentration of H_2S, an appropriate material may be used such as high grade stainless steel, ferrocement, HDPE, fibreglass or fibre reinforced plastics (FRP). All of these materials are appropriate to prevent SSBC systems from undergoing corrosion. If galvanized steel or mild steel are used, the potential for corrosion can be minimized by applying protective coatings, and cathodic protection.

2.9.5 UV exposure

As is the case with any anaerobic cover, SSBC material is also exposed to ultraviolet radiation exposure over the life of the system. The UV radiation from the sun can penetrate the material causing degradation of the polymers, which impacts the durability of the cover material. The type of materials selected for the construction of SSBCs can withstand UV exposure. Stainless steel, galvanized steel and light aluminium covers are not affected by UV exposure. If HDPE, FRP and fibreglass are used as cover materials, there is a potential for damage due to UV radiation. However, if UV stabilisers are added to the polymers, there will be an increased UV resistance. Some HDPE liners have been in service for over 20 years in mining tailings dams, and similar projects in the Pilbara and other regions where there is a high UV radiation. In the case of FRP cover material for SSBC, polyester resins based on neopentyl-glycol (NPG) that have proven to have superior UV resistance will be used.

2.9.6 Rainwater management

The modular design of the gas covers facilitates discharge of the collected rainwater to the channel or to the reactor. The smaller plan area of the gas covers in contrast to the conventional single cover system avoids ponding of rainwater on the cover. The excess water in the channels will be discharged to either the reactor or to an external rainwater collection tank for beneficial use.

2.9.7 Rise and fall of the water level

Unlike conventional fixed covers, the SSBC system is a flexible, freely floating system so the rise and fall of the water level does not affect the system. The SSBC system is not fixed to the reactor / pond base or sidewalls. The system is designed to use buoyancy and entrapped gas pressure to float on the water column, without being toppled by wind, rain or rise or fall of water.

2.9.8 Thermal expansion and contraction effects

As the SSBC system is a modular system, the sides of the cover are not fixed to the sidewalls of the pond/reactor and thus thermal expansion and contraction have little effect on the covers. In the case of a conventional fixed cover system where the cover is sealed to the pond or reactor walls, given the larger size of such covers, the thermal expansion and contraction have serious detrimental effects and cause strain to the cover material.

2.9.9 Installation and commissioning restrictions

The installation and commissioning of a fixed cover to an anaerobic lagoon is a complex process. As the entire lagoon is covered by a single cover, any location of leakage due to an improper seal between the liner of the lagoon and the cover material is very difficult to detect for repairs. If it is a new system, it would be difficult to determine if the lack of gas pressure/collection from the lagoon is due to leakage through the gas cover or due to an anaerobic process fault. To pinpoint the exact location of the source of a leakage will be a challenging task. When covering an existing lagoon or reactor, there is potential for leakage of biogas through the seal between the cover material and the liner or embankment increases, as often the seal may not work properly. The cost of such installations will be much higher due to the potential risks and consequential responsibility of the contractors.

In the case of the SSBC, as it is a modular floating system, the sides are not welded or sealed to the reactor walls or lagoon liners or buried on the embankment with concrete. If an individual gasholder is not rising due to lack of gas pressure, it can be assumed that there is some leakage through the cover of that gasholder. The individual cover can be removed easily for repair. If there is a process malfunction and no biogas is produced, none of the gasholders will be rising at all, and the operator can focus troubleshooting the anaerobic reactor/lagoon process (such as raising the pH, alkalinity etc.). The installation and commissioning of the covering system is much simpler and can be managed using local resources such as the maintenance team of abattoirs. In addition, the risk based cost escalation will be relatively lower in the case of SSBC in contrast to the conventional fixed type covers.

2.9.10 Ease of in-service repair

For SSBCs, individual gas covers can be removed without much difficulty and repaired for any faults. In the case of tall reactors, the individual cover that requires service can be removed using a crane if no operator access bridge is available. The water level and pressure regulating mechanism of gas covers can be managed remotely using a control system.

2.9.11 Wind force

One of the main disadvantages of covered aerobic reactors that use fixed covering systems is that they are very prone to damages due to wind forces. The SSBC system has been designed to manage the impact of wind forces. The individual covers are designed to resist toppling due to wind forces, and the height above the reactor/pond liquid level can be managed remotely to avoid any problems with higher wind forces. As the covers are not fixed to reactor walls, there is no scope for tearing and damage to the covers.

2.10 Construction Materials for SSBC system

The SSBC system can be fabricated with a number of conventional materials. The selection of materials depends on several parameters such as the type of model selected, local environmental factors, overall budget for the covering system, required life span of the covering system, O&M budget and manpower available, access to construction equipment on the site for installation and future maintenance, access to the perimeter of the reactor/lagoon, gas pressure required (without the use of a root blower) and storage volume required for biogas.

The type of fabrication materials includes stainless steel, galvanized steel, ferrocement, high density polyethylene (HDPE) and fibreglass covers on a structural element. Fibreglass glass is a composite material, with reinforcement of structural steel or PVC pipes where required. The covering system also incorporates materials for buoyancy, including polystyrene foams and sealed PVC pipes. A summary of the materials used for fabrication is provided in Table 1 below.

2.10.1 Ferrocement

As the SSBC technology is a modular system, ferrocement is a suitable construction material, particularly for application in anaerobic lagoons. Each module may be approximately 1 tonne and will require a crane for installation. The ferrocement modules can be constructed on site, and repairs in case of any local damage are relatively easy. The cost of construction will vary depending upon the site.

2.10.2 Stainless steel

Stainless steel (SS) is an appropriate material for SSBC provided its weight is negated by the gas pressure. SS can withstand the corrosive environment near the external side of the SSBC system. The UV and fire resistance, lower maintenance cost and long life span are the main advantages of using SS as material of construction for the SSBC. However, the capital cost of SS is the highest in comparison to the other materials.

2.10.3 Galvanized iron

Galvanised iron has properties similar to stainless steel, except that it has a lower corrosion resistance. Zinc coating in these materials is prone to corrosion by sulphur acids produced from hydrogen sulphide (Kronos ecochem, 2014). Applying a protective coating such as paint can alleviate the problem. However, there is a chance of paint being damaged by the roof rubbing against an adjacent roof or platform during operation or maintenance. Despite this the material should still be considered, as it is cheaper than stainless steel.

2.10.4 High Density Polyethylene

High Density Polyethylene (HDPE) is manufactured from the semi-crystalline polyethylene (PE) family. HDPE is a very light and extremely tough, chemically resistant plastic. It does not absorb water, has good sliding abrasion resistance and is self-lubricating. Other superior properties include long term material strength, exceptional weld strength, good acid resistance, improved environmental stress cracking resistance and shorter welding times. It is easier to bend as it is manufactured in thinner sheets and it is also weatherproof with exceptional UV stability. HDPE is the preferred material in covering anaerobic ponds in the meat industry due to its strength, good

UV and FOG resistance (Meat Technology Update, 2010). HDPE is cheaper and can be successfully used to make covers stretching the entire lagoon.

2.10.5 Fibreglass

Fibreglass, also known as glass reinforced plastics (GRP) or fibre reinforced plastics (FRP), is also a suitable material for SSBC. The glass fibre may be randomly arranged, flattened into a sheet (called a chopped strand mat), or woven into a fabric. The plastic matrix may be a thermosetting plastic usually an epoxy, polyester resin, vinyl ester, or a thermoplastic.

Fiberglass is a strong lightweight material, its bulk strength and weight are also better than many metals. It can be more readily moulded into complex shapes, making it an ideal material for SSBC systems. The material can be fabricated in a factory in parts and can be transported to the site in a convenient manner. There will be minimum site work required to assemble the parts to complete fabrication.

2.11 Life expectancy

The life expectancy of SSBC system depends on the type of material of construction. If SSBC is made up of stainless steel, fibreglass and HDPE, the system will have a life expectancy of over 20 years. Galvanized iron covers may have a shorter life span, but regular maintenance can increase the life span similar to that of the other materials. The components of the SSBC system such as gas pipes and fittings will have the same level of life expectancy as conventional gas covers. SSBC systems require annual service maintenance for replacing damaged fittings, washers etc. as is the case with conventional covering systems.

2.12 Typical costs

The typical cost of an SSBC system varies with respect to the material of construction, dimensions and application. For example, the cost of covered lagoons will be relatively cheaper than elevated tanks due to cost of installation. The typical cost of a stainless steel SSBC system for a reactor will be in excess of $800,000, whereas a GI based system will be above $550,000. In contrast, a HDPE or Fibreglass system will be over $400,000. A ferrocement gas holding system may cost about $400,000.

Table 1: Comparing different materials for SSBC construction

Material	Specific Gravity	Cost	Material Degradation	Strength	Ease of fabrication	Yield Stress (MPa)	Minimum Thickness (mm)
SS	Very high 7.8	Costly	Stable	Strong	Good	205[a]	0.015
GI	Very high 7.8	Relatively costly but cheaper than SS	Not entirely corrosion resistant	Strong	Good	205[a]	0.02
Fibreglass	Low 1.87	Moderate	Good FOG resistance, reasonable UV and weather resistance	Moderate	Good	55[d]	0.055
HDPE	Very low 0.97	Less expensive	Chemically robust	Ductile	Good (factory made)	26[b]	0.115
Ferrocement	High 2.6	Moderate cost	Coating required to prevent chemical corrosion	Moderate resistance	Labour intensive	10.34[c]	10

a. For stainless steel, grade 304 (Azo Materials, 2016), grade 316 (Global Metals)
b. (Aliaxis Company, 2010), (Polymer industries)
c. (Canby, 1969),
d. (Materials, 2004), (Matweb, 2016)

2.13 Features of the SSBC technology

Self-regulating suspended biogas collector (SSBC) technology overcomes the drawbacks of the current technologies of biogas covers/collectors of anaerobic digesters. The SSBCs are constructed in a modular fashion, each module can float independently, and can be retrofitted to an existing reactor/lagoon. They can provide variable gas pressure or storage volume, and any damage to one of the modules can be fixed without shutting the digester down. Additionally, digester problems such as excessive crust formation and servicing of the mixers can be easily managed with SSBC technology. The system can also manage extreme wind, cyclone and rainfall events with no or minimal damage which again can be rectified without shutting down the digester in contrast to the conventional systems.

The method of implementing SSBC can be broadly divided into two:

(i) Positioning the gasholders on a crisscross platform
(ii) Self-balanced individual floating roof.

In the case of the first method, gasholders are placed in the channels of water on a platform. The platforms are in turn supported by the buoyant force. This is a more robust model as the movement of gasholders is tightly restricted within the channels. However, this method of construction involves more materials and is hence heavier and costlier than the second method.

The second method relies on self-balancing of individual units to maintain stability. The effect of wind is more critical for the second model. The design includes safety margins to guarantee the stability of roof in strong wind conditions. The roofs are also likely to collide against each other, which necessitates the use of shock absorbers in the form of protective pads around the circumference. Regular inspections will be required to ensure the structural integrity of both the roof and the protective padding.

As can be seen in Figure 21, the channels in the platform are filled with water. The intention is to prevent the leakage of gas through the sidewalls. The channels are connected to a water supply line through a level control device like a float valve to compensate for the loss of water due to evaporation. The SSBC roofs can be lifted using a crane if need be during maintenance. The live weights used for internal pressure on top of the gas cover can be removed one by one before the roof is finally taken out. The design ensures the safety of personnel walking over the roof for maintenance activities.

The gas generated from an individual gasholder is directed to a main pipe that takes it to a storage tank.

The weight of the roof is an important factor mainly because of two reasons. Firstly, along with the cross sectional area of the roof, it determines the pressure of the gas contained inside the roof. However, this weight can also be provided by the addition of weights at a suitable position on the roof.

The size of the individual gasholder is determined based on the type of material and the internal pressure required. Decreasing the plan area of the gasholder reduces the submergence depth and increases the gas pressure. However, an increase in cost is expected in this case.

An assessment was carried out to study the performance of different materials – Stainless steel, HDPE, ferrocement and fiberglass. The performance is measured in terms of the submergence depth of the platform and the internal gas pressure due to the weight of the gasholder. The thickness of the roof and channel were taken as 4 mm and 2mm for Stainless steel, 15 mm for HDPE, 12.5 mm for ferrocement and 10 mm for fiberglass.

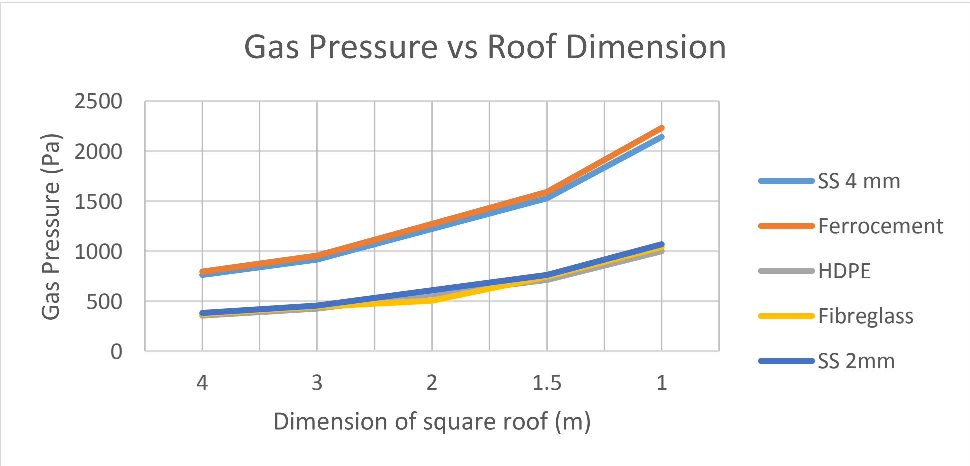

Figure 22: *Internal gas pressure versus roof dimension*

From Figure 23, it can be seen that stainless steel (4mm thick) and ferrocement structures require unrealistically high channel submergence depths. This rules out their use in the construction of the roof and channel. A stainless steel structure of 2 mm thickness provides reasonable submergence depths. From the discussion on minimum roof thickness requirement (Table 1), it is clear that a 2 mm thickness is sufficient to withstand internal gas pressure. However, other design considerations are expected to influence the roof thickness.

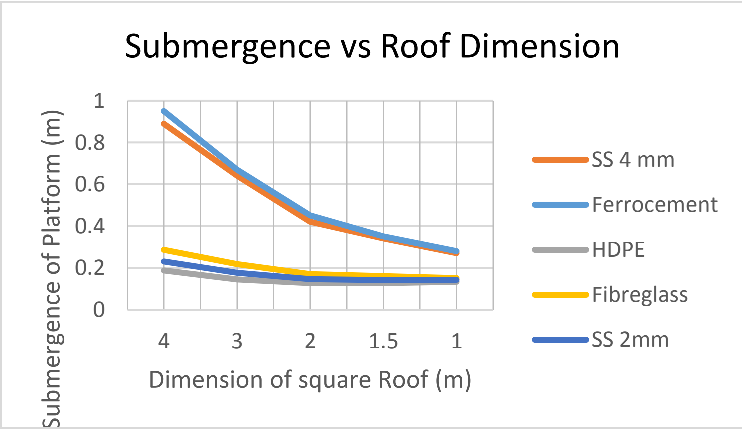

***Figure 23*:Submergence versus roof dimension**

Fibreglass and HDPE are also good candidates as they provide reasonable submergence. HDPE provided the least submergence. In the case of HDPE, fibreglass and stainless steel (2 mm), the submergence of the platform decreases for a 4 m x 4 m plan area to a 2m x 2m one. However, decreasing the dimension of the roof from 2 m does not result in any significant decrease in submergence depth. Also the decrease in submergence depth with these materials is at a much lower rate than that of ferrocement or 4mm thick stainless steel.

Decreasing the roof dimension also helps to improve internal gas pressure. This will reduce the amount of extra weight needed on top of the roof. However, the available space for weight addition is also less.

Therefore, decreasing the plan area of the gasholders reduces the submergence depth and increases the gas pressure, both of which are desirable. However, an increase in cost is expected in this case.

2.14 Design of SSBC system for DBC plant

The vertical reactor, EEI's High-rate Anaerobic Reactor Technology (HART), is an open tank measuring 32 m in diameter and 6 m in height. The tank is constructed of bolted steel, with an internal HDPE liner for preventing any contact between the liquid contents of the tank and the steel structural material as well as any leaks.

*Figure 24: **Structural wall of the EEI HART system at DBC***

The design of the biogas collection system for the HART installed at DBC should consider the complexity of the dual materials of the reactor walls as shown in Figure 24. Constant contact of the gas holder against the HDPE liner may weaken it and this can damage both the reactor and the gas holders in the long term. A tear or hole in the HDPE liner or the gas holder can render it inoperative. Constant striking of the gas holder against the reactor wall can damage the bolted steel structure. It can also puncture the gasholder, which will affect its gas holding capacity. The reactor fittings, such as the inlet, outlet and crust breaking water jet sprayer require that the gap between the gasholders and the reactor walls be about 300 to 400 mm as shown in Figure 25.

The HART system does not have any walkways around the tank, which limits the access to the gas holders.

***Figure 25*:HART system fully constructed**

The covering system for capturing biogas should consider both the installation and ongoing maintenance, particularly because of limited access to all sides of the tank.

2.14.1 Selected design of SSBC system

This section covers identification of a suitable design of the EEI-SSBC system for retrofitting DBC's anaerobic reactor including modular design concepts, interconnection of individual gas collectors, materials of construction and prevention of gas leakage.

Considering the constraints of the anaerobic reactor tank, we selected the SSBC – Model 3. This model considers the lack of access to the central areas to periodically service the gas outlet connections and other system components. The maintenance of gas outlet connectors can be carried out along the sides of the reactors (either using a crane or by providing an additional walkway around the perimeter of the reactor).

The material to be used in the construction of the SSBC system for DBC is fibreglass, reinforced with steel rectangular channels. A typical cross section of the modular gas holding system is shown in Figure 26. Each gas holder is 3 m wide, while the length of each gas holder varies, but will be the chord length of the reactor.

Each gas holder is to be installed with buoyant materials to facilitate flotation when there is no biogas inside the gas holders. The stability of the gas holder is ensured by installing a water tank, at the centre of each gas holder. The water channel also provides sufficient gas pressure inside the gas holder (2kPa) so that the biogas can be transferred to the generator or storage tank easily. If the downstream gas pressure required is substantial, a root blower will be required to facilitate transfer of the biogas from the gas holders. The water level can be adjusted to increase or decrease the internal gas pressure and in case of storm events, the gas holder can be lowered by increasing the water level.

There will be ten individual gas holders – the maximum span of the gas holders is 31 m and the minimum span is 18.6 m. Each individual gas holder will have two gas outlets on either side of the water channel. A single gas pipe will connect these two outlets to maintain equal gas pressure in both sides of the gas holder. All the gas outlets of the individual gas holders can be connected to a larger pipe to supply to a downstream gas storage unit, electricity generator or gas flare stack. This way, it can be ensured that all the gas holders will maintain the same pressure. Furthermore, each gas holder will be provided with isolation valves on the gas lines for any repairs or maintenance services.

The roof/top of the gas covers is designed to minimise the impact of wind forces. Similarly, the rainfall will be captured in the water channel and any excess water will overflow to the reactor. The water level in the water channel can be regulated remotely to increase the gas pressure and to lower the gas holder to minimise impacts due to storm events.

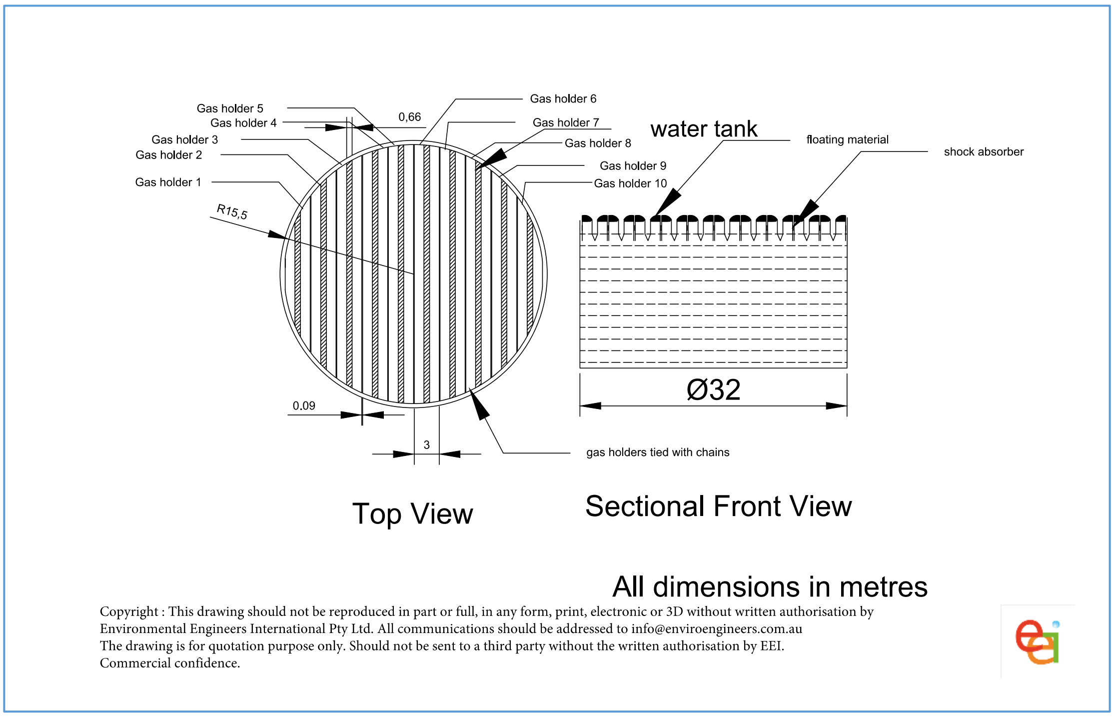

***Figure 26*: Layout of the gas holders**

Each gas holder has a shock absorber on each side, so that any collision between gas holders will not damage the side walls. The gap space between the individual gas holders is 90 mm. In order to capture the biogas that may be lost to the environment from this gap space, alternative gas holders have 140 mm inclined extensions at 55^{o} to the vertical. Any gas bubbles rising through the water column in the 90 mm gap space will be channelled to the gas holder. There is a gap of 500 mm from the end of the reactor wall to the gasholders to prevent any damages to the fittings on the reactor walls and the gas holders. The end sides of the gas holders have provisions to connect to the reactor walls with a flexible cable if needed. Similarly, along the length of the gas holders, flexible connections can be attached between the gas holders to minimise drifting during extreme winds.

As stated earlier, the material of construction of the gas holders is fibre reinforced plastics. Considering the span (as much as 31 m) of the gas holders, each gas holder will be provided with adequate reinforcement, but embedded in fibre glass. The buoyant material which will provide sufficient buoyancy to the gas holders during the periods that they hold no gas will be polyurethane covered in a fibreglass coating to prevent any contacts with the contents of the wastewater in the reactor such as fat, oil and grease.

Although the reactor is not covered with a single gas holder and there is a gap between individual gas holders, the biogas generated will be fully collected except for the 500 mm gap between the reactor wall and the end of the gas holders. This gap is essential as there are a number of inlet and outlet pipe connections and other installations such as testing valves in that space. Any gas bubbles that rise up in the gap between gas holders will be collected and directed to one of the gas holders using the sloped side wall. The gas fittings, connections to the gas holders and gas pipes should be periodically inspected and any damages to the fittings are to be rectified as in the case of any other projects. We recommend the construction of a walkway, at least on the same half of the perimeter as the gas holders so that periodic checking and maintenance services could be carried out to ensure that there is no gas leakage at all during operation of the system.

3 Lessons Learned

In this project, EEI has discussed the current state of technology with regards to covering technologies for capturing biogas from anaerobic lagoons and vertical reactors, assessing their performance, applicability to the meat industry including the economic factors. The EEI Self-regulating Suspended Biogas Collector (SSBC) technology has been assessed alongside the conventional methods of biogas collection from anaerobic systems, and this report has presented an objective review of each technology in order to determine the solution best suited to the red meat industry.

With consideration to both anaerobic lagoons and anaerobic vertical reactors, a number of existing covering technologies were analysed before EEI reached a decision. For anaerobic lagoons, modular covers have the potential to overcome many of the drawbacks of typical and more popular fixed and floating systems. For example, modular covers are easier to repair and maintain, can be installed incrementally, have a longer lifespan and may potentially require less capital although overall costs may be significant. However, as the design of such systems is considerably complex, there has been little evidence in terms of practical applications of modular designs that can confirm their commercial viability. As it stands, the most appropriate cover will depend on the specific project at hand. For example, floating covers allow for easier desludging, sludge removal, variations in water level and it is easier to retrofit existing lagoons with them. This comes at the cost of a number of disadvantages not present with fixed covers such as higher capital expenditure, limited choice in construction materials and uplift due to wind.

With regards to vertical anaerobic reactors, there are a number of both fixed and floating cover designs currently used within the industry. Fixed covers may be constructed using a variety of techniques and materials. As in the case with anaerobic lagoons, the fixed covers for vertical reactors are more difficult to repair, as the reactor must be emptied. Their inability to tolerate changes in liquid levels inside of the reactor is another concern. Damage to the supporting structure or the cover itself is likely to occur if influent and effluent volumes are not constant. Gas leaks at the interface of the cover and wall may also occur, as well as corrosion of the supporting framework inside the reactor, particularly when H_2S gas is present.

Self-regulating suspended biogas collector technology overcomes many of the issues present in current anaerobic digester covers which have been previously discussed. As a modular design, SSBCs can provide variable gas pressure or storage volumes. The modular nature of the system also means repairs can be carried out on any single damaged module, without having to shut down the entire digester. Resistance against extreme weather conditions is another benefit to the SSBC technology, as is the ease of management of crust formation which is present in anaerobic systems treating meat industry effluent. An SSBC can be constructed using a combination of materials depending on a number of factors such as the local environment, budget and required lifespan. Stainless and galvanised steel, ferrocement, HDPE, fibreglass and PVC are among the materials which may be used.

For the purposes of retrofitting DBC's anaerobic reactor, the most appropriate SSBC design as selected by EEI is a steel reinforced, fibreglass modular structure. The SSBC is designed with the following issues in mind:

- Rainwater management
- Rise and fall of water level
- Thermal expansion and contraction effects
- Avoiding blocking of gas collection paths
- Wind resistance
- Installation restrictions
- Ease of in-service repair
- Cost
- Floating crust
- Extreme weather
- Operation & maintenance
- Corrosion

4 Bibliography

Aliaxis Company, 2010. *HDPE Physical Properties.* [Online]
Available at:
http://www.marleypipesystems.co.za/images/pdfdownloads/productbrochures/hdpe-physical-properties.pdf
[Accessed 25 January 2016].

Azo Materials, 2016. *Stainless Steel Grade 304.* [Online]
Available at: http://www.azom.com/article.aspx?ArticleID=965
[Accessed 25 January 2016].

Canby, D. C., 1969. *Ferrocement with particular reference to marine applications.* [Online]
Available at:
http://deepblue.lib.umich.edu/bitstream/handle/2027.42/91654/Publication_No_014.pdf?sequence=1
[Accessed 25 January 2016].

Global Metals, n.d. *Stainless Steel 316/316L.* [Online]
Available at:
http://www.globalmetals.com.au/_pdf/Stainless_Steel/Stainless_Steel_316.pdf
[Accessed 25 January 2016].

Kronos ecochem, 2014. *KRONOS INTERNATIONAL, Inc..* [Online]
Available at:
http://www.kronosecochem.com/ehome_en.nsf/Multi%20Media%20Files/ADB0C38C533E747385257B

Laginestra & Allan (2014), Application of Covered Anaerobic Lagoons for Pretreatment of Wastewater in Red Meat and Other Industries, GHD, Proceedings of IWA Conference of Pre-treatment of Water and Wastewater, May 18-21, 2014, Tongji University, Shanghai.

Lewers, GM (2010) Design of a Frame/Structure for a Large Wastewater Treatment Pond, B.Eng (civil) Research Project Report, University of Southern Queensland, pg 65.

Materials. (2004, June 17). Retrieved January 25, 2016, from http://homepages.which.net/~paul.hills/Materials/MaterialsBody.html

Matweb. (2016). *Fibreglass Epoxy Laminate Sheet.* Retrieved January 24, 2016, from http://www.matweb.com/search/datasheet.aspx?matguid=8337b2d050d44da1b8a9a5e61b0d5f85&ckck=1

Meat Technology Update. (2010, October). *Covered Anaerobic Ponds.* Retrieved December 17, 2015, from http://www.ampc.com.au/site/assets/media/Factsheets/Climate-Change-

Environment-Water-Waste-Energy-Sustainability/MTU_2010_Covered-anaerobic-ponds.pdf

MIRINZ (1991). "Effluent treatment in the Australian meat industry M.050." Meat and Livestock Australia, pg 63.

MLA (2009), Anaerobic Cover Material Vulnerability, - Assessment of Available Cover materials, A.ENV.0072, North Sydney

Polymer industries. (n.d.). *Densetec HDPE sheet- Typical Properties.* Retrieved January 24, 2016, from http://www.polymerindustries.com/pdf/tp_hdpesheet.pdf

US EPA (1997), A Manual For Developing Biogas Systems at Commercial Farms in the United States, AgSTAR Handbook – First edition, EPA-430-B-97-015