Liquid Manure Storage Covers

Final Report

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Introduction

Every livestock operation requires some kind of manure storage. Manure is typically stored so that it may be used as a nutrient source for crops - allowing for spreading at the appropriate time. Most livestock manure is handled as either a liquid or as a solid. Liquid manure may be defined as having a moisture content greater than 82% (OMAFRA, 2005). It is commonly stored in either concrete tanks or earthen basins. During storage, biological activity occurs in the manure. Methane, ammonia, hydrogen sulfide, and carbon dioxide are four important gases produced from decomposing manure (FSA, 2002). The release of these and other gases has environmental consequences, mainly associated with odour, loss of nutrients and release of gases responsible for global warming. Livestock manure may account for six to 10% of the annual global emissions of methane, a greenhouse gas (Sommer et al., 2000). Ammonia can contribute to acid precipitation. Hydrogen sulfide poses a health and safety risk to humans and livestock. About 25% of the total odour emission from an animal facility comes from the manure storage (Zhang and Gaakeer, 1998). Therefore, reducing emissions from a manure storage can have environmental benefits.

Covers for liquid manure storages significantly reduce odour and gas emissions by creating a physical barrier between the liquid and the air. Zhang and Gaakeer (1998) include covers in their list of methods to effectively reduce odour emissions from storages.

Covers are classified as either impermeable or permeable. Impermeable covers do not allow any gases coming from the manure to be emitted to the atmosphere. On the other hand, permeable covers permit transmission of some gases. Various types of covers have been tried and each has its own advantages and disadvantages. The following covers will be discussed in this report:

Permeable:
- a) Straw
- b) Geotextile
- c) Clay Balls
- d) Perlite
- e) Rigid Foam
- f) Oil
- g) Natural Crust
- h) Corn Stalks, Sawdust, Wood Shavings, Rice Hulls, Ground Corncobs, Grass Clippings

Impermeable:
- a) Inflatable Plastic (positively pressurized)
- b) Floating Plastic (negatively pressurized)
- c) Floating Plastic
- d) Suspended Plastic
- d) Concrete
- e) Wood/Steel

Permeable Covers

Permeable covers are less expensive than impermeable covers but they do not last as long and are not as effective at reducing the emissions of odours and gases.

a) Straw - Straw covers are popular because they are cheap and fairly effective at reducing emissions. The straw forms an organic floating mat on the manure surface. There is no significant difference between the performance of barley or wheat straw covers (Nicolai et al., 2002).

Odour reduction with straw covers will vary from 90% for a thick, newly applied cover to 40% or less depending on straw thickness and uniformity (Nicolai et al., 2002). University of Minnesota researchers (Clanton et al., 2001) have shown that a 10 cm thick layer of straw reduces odours by 47%, a 20 cm layer by 69% and a 30 cm layer by 76%. Another study showed that a straw cover varying in depth between five and 15 cm reduced odour emissions by about 84% (Hornig et al., 1999). Straw covers reduce hydrogen sulfide emissions by 80 to 95% (Bicudo et al., 2003). Xue et al. (1999) found that a five to 10 cm thick layer of straw, along with a naturally forming crust on dairy manure, suppressed hydrogen sulfide emissions by 95%. The effectiveness of straw at reducing ammonia emissions varies widely - between 25 and 85% (Nicolai et al., 2002). With a straw depth of 5 to 15 cm, ammonia emission was shown to reduce by 80% (Hornig et al., 1999). A different study using the same thickness, along with a natural crust, showed a 95% reduction (Xue et al., 1999). Sommer et al. (2000) found that a straw cover was more effective than a natural crust or Leca® pebbles at reducing the emissions of methane.

The effectiveness of straw covers reduces with time, due to the saturation and sinking of the straw. Straw covers usually last between two and six months, depending on the amount applied (depth), evenness of application, basin size, and climatic conditions of the area (Bicudo et al., 2003). Most storage basins successfully using straw covers are located in the western United States and Canada where the amount of precipitation is less than in other livestock areas of North America (e.g. Ontario). Since the straw eventually sinks, a chopper pump is required so the pumping system does not get blocked when emptying the manure storage (Zhang and Gaakeer, 1998).

Figure 1 Blowing straw on to a manure storage basin (Bicudo et al., 2003)

The straw is applied to the manure storage using a straw blower, as seen in Figure

1. Using this method, it is difficult to judge the thickness of the straw and apply it evenly. The recommended thickness of straw is 30 cm (with a minimum thickness of 20 cm). Even though little additional odour, hydrogen sulfide, and ammonia reduction is gained by increasing the thickness to 30 cm, a thickness of 30 cm is needed to keep the straw afloat or keep the upper portion dry. This allows the straw to absorb gases and act as a biofilter (Clanton et al., 2001).

The amount of straw needed depends on the area of the manure storage and the desired depth of the straw layer. A single large round straw bale (1.8 m diameter) can cover about 47 m^2 with a 30 cm layer (Nicolai et al., 2002). A 25 to 30 m diameter storage tank with a 30 cm layer of straw would cost CDN$110 to $154 at CDN$11 per bale. Sometimes oil is added to the straw at the time of application to increase the longevity of the cover (Clanton et al., 1999). In summary, straw has been proven to be an effective short term solution to odour and gas emissions.

b) Geotextile - Geotextile covers are alternatives to straw covers. These covers are non-woven fabric, composed of thermally bonded, continuous polypropylene filaments. Polypropylene is resistant to rot, moisture, and chemical attack (Clanton et al., 2001). The performance at reducing emissions is variable. Nicolai et al. (2002) have documented odour reductions of 40 to 65%, hydrogen sulfide reductions of 30 to 90%, and an ineffectiveness at removing ammonia. Bicudo, et al. (2004) showed that a geotextile cover reduced odours by 50%, hydrogen sulfide by 72%, and ammonia by 30 to 45%. In contrast, Clanton et al. (2001) demonstrated that geotextile fabric was not statistically effective in reducing odour and gases.

Figure 2 Opening for the access of agitation and pumping equipment in a geotextile-covered manure storage (Bicudo et al., 2003)

Any effectiveness in reducing odours and gases decreases over time compared to straw, because the fabric becomes plugged with biomass growth. This creates an impermeable barrier that allows gases to build up and move to open spaces along sidewalls, where they are vented (Bicudo, et al., 2004). Geotextile thickness has no impact on odour and gas emissions (Clanton et al., 2001).

Problems have been encountered in the spring, when the snow melts and the covers are saturated with water and manure. They may no longer float. Some covers may be completely submerged (Bicudo, et al., 2004). These researchers also found that management and safety were challenging during agitation and pumping. Many types of agitation equipment pump manure over the surface to help with the stirring but this is not possible with geotextile covers. To agitate, the cover must be partially removed, typically from one corner of the basin. Alternatively, the cover is lifted by a cable and winch system and the agitation/pumping equipment is positioned under the cover (Nicolai et al., 2002). Neither of these options allows for vigorous agitation. Procedures and equipment to agitate under the cover through an access opening are being developed (Nicolai et al., 2002). Figure 2 shows an opening for agitation.

The disposal of geotextile material after its usable life (three to five years), can be costly (Nicolai et al., 2002). One producer paid US$1000 for pick-up and hauling and US$800 in landfill fees, although numbers will vary (Bicudo et al., 2003). Adding a layer of closed-cell foam between two types of geotextile materials has doubled the life of the covers and prevented sinking - see Figure 3 (Nicolai et al., 2002). Also some geotextile covers are protected against UV radiation, which reduces deterioration from the sunlight, thus increasing life expectancy (Bicudo et al., 2003). Geotextile covers cost between US$1 to $1.30/m^2 (Nicolai et al., 2002). Bicudo, et al. (2004) estimated the cost to be slightly higher, at US$1.50 to $2.40/m^2. Using these numbers, the cover for a 50 m by 50 m tank would cost in the range of US$3750 to $6000.

Figure 3 Geotextile floating permeable cover with closed-cell floatation (Nicolai et al., 2002)

c) Clay Balls - Air-filled clay balls can also be used as a floating cover. These are low density spheres with minute independent closed air cells surrounded by a tough outer shell making them impermeable to water and other fluids (Clanton et al., 1999). Leca® (lightweight expandable clay aggregate) and Macrolite® are two brands of clay balls (Nicolai et al., 2002). Leca® pebbles reduced 90% of the odour and were 65 to 95% effective at reducing ammonia emissions, while Macrolite® pebbles reduced only 60% of the odour and were 64 to 84% effective at reducing hydrogen sulfide emissions (Nicolai et al., 2002). Leca® pebbles were also shown to significantly reduce methane emissions (Sommer et al., 2000). Berg et al. (2006) established that Leca® with saccharose reduced methane emissions by 10% and lactic acid was even more effective. In one experiment, the clay balls ranged in diameter from 1.9 to 2.5 cm and were placed to a depth of 20 cm (Clanton et al., 1999). Results showed that the clay balls reduced emissions but not as well as straw, oil, geotextile, and PVC/rubber covers. Reducing the diameter to reduce void volume and increasing the thickness may help to significantly increase the effectiveness (Clanton et al., 1999).

Clay balls last for approximately 10 years, which is significantly longer than straw and even geotextiles, but when they eventually sink into the manure, they form clumps and can plug the pumping equipment (Funk et al., 2004). Both Leca® and Macrolite® cost about US$13 /$m^2$ (Nicolai et al., 2002).

d) Perlite - Perlite is a white, buoyant naturally-occurring siliceous mineral (Hornig et al., 1999). One brand that has been tested as a manure storage cover is Pegulit® - see Figure 4. In a study by Hornig et al. (1999), Pegulit® granules were spread over the manure surface with a blower to a thickness of 10 cm. Results showed that this cover reduced odour emissions between 30 and 93%. Ammonia emissions were reduced by 63 to 91%, depending on the type of Pegulit® (Hornig et al., 1999).

Pegulit® usually lasts for 10 years before it needs replacing and costs about US$1.30 to $2/$m^2$/year (Hornig et al., 1999). The ability of Pegulit® to float quickly back to the surface after mixing is one clear advantage over straw.

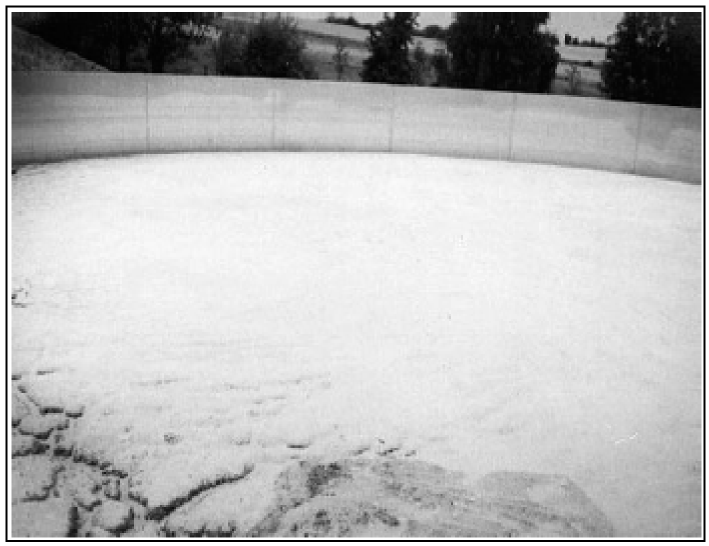

Figure 4 Pegulit® as a covering for a 16m diameter storage container (Hornig et al., 1999)

e) Rigid Foam - Miner et al. (2003) evaluated the effectiveness of a 5 cm thick composite cover made from recycled closed-cell polyethylene foam chips topped with a geotextile layer containing zeolite particles. Under field conditions, the cover survived severe storms and allowed intense rainfall to pass through without causing inundations. The cover also eliminated odour and reduced ammonia emissions. Miner et al. (2003) compared the effectiveness of four different covers at reducing ammonia emissions. The full foam cover reduced ammonia by 70%, half the cover reduced ammonia by 55%, the cover plus geotextile reduced ammonia by 77%, and the cover plus zeolite reduced ammonia by 82%. It was clear that the presence of zeolite improved the cover's effectiveness.

Microbial populations were found on the cover after four months of use and since an aerobic bacterial population is essential for ammonia oxidation, the cover tended to become more effective with time (Miner et al., 2003). The surface of the cover also became covered with algal populations within two weeks of installation but this vegetative growth had no discernible impact on the performance of the cover. Thicker covers achieved a greater ammonia reduction than thinner ones. These foam covers have a 10 to 20 year life expectancy (Miner et al., 2003).

Ethafoam® 220 was tested by DeVries et al. (1980) by placing 3.2 and 5 cm thick layers in concrete storage tanks. Installation involved welding the planks together and then placing a layer of crushed stone on the cover to resist wind uplift. This process was complicated and labour intensive and there were a number of failures during the experiment itself. The results showed that the cover reduced odours effectively, except in strong winds. However, no gas emission reductions were measured.

Ethafoam® 220 can be ignited by contact with a flame. Under normal combustion, carbon monoxide and dense smoke are generated. Ethafoam® is also a good electrical insulator, therefore accumulation and discharge of static electricity is possible. However, methane quantities are low and no known explosions have occurred so static electricity is not considered a problem. Ethafoam® deteriorates when exposed to sunlight. Life estimates are placed at five years for white Ethafoam® and ten years for black (DeVries et al., 1980).

f) Oil - Rapeseed oil was applied at thicknesses of 3 and 6 mm to evaluate its effectiveness as a cover (Hornig et al., 1999). Ammonia emissions were reduced 85% with the 6 mm thick oil layer, while the 3 mm layer showed an insignificant effect (Hornig et al., 1999). Clanton et al. (1999) discovered that the use of a soybean oil mat of 10 mm thickness produced a distinctive offensive odour. This may be due to the high carbon concentration of oil mixing with the nitrogen of the manure. Clanton et al. (1999) concluded that oil should not be used alone as a cover.

g) Natural Crust - Natural floating covers are those formed by the fibrous material contained in the manure (Bicudo et al., 2003). Dairy manure usually contains high amounts of such material and therefore a natural crust is common on the surface of dairy manure. Stored swine manure can sometimes develop a natural crust but its consistency is much different from dairy manure (Bicudo et al., 2003). Sommer et al. (2000) found that a 7 to 10 cm thick cover developed naturally over the cattle manure in a concrete tank. This crust reduced methane emissions by 38%. Bicudo, et al. (2004) found that natural crust can be at least as effective as a geotextile cover in reducing emissions of hydrogen sulfide. There was no indication of the effectiveness of natural crusts at reducing odours. Bicudo et al. (2003) concluded that the effectiveness of natural crust at reducing odours and gases was difficult to quantify. So much depends on the thickness and other physical properties of the crust. The effectiveness varied in the range of 10 to 90%. A natural crust only has a life expectancy of two to four months (Bicudo et al., 2003).

h) Corn stalks, Sawdust, Wood Shavings, Rice Hulls, Ground Corncobs, Grass Clippings - Artificial floating organic covers, also called biocovers, include chopped corn stalks, sawdust, wood shaving, rice hulls, ground corncobs, and grass clippings (Bicudo et al., 2003). Covers made of rice hulls with oil resulted in the lowest ammonia and hydrogen sulfide emissions at 31 and 4% respectively (Clanton et al., 2001). Grass clippings with oil produced the least odour emissions, followed by corncobs with oil, corn stalks with oil, and rice hulls with oil (Clanton et al., 2001).

Impermeable Covers

a) Inflatable Plastic (positively pressurized) - Impermeable covers (see Figure 5) are more expensive than permeable covers but they have a longer life expectancy and are more effective at reducing odours and gases. In order to construct an inflatable plastic cover, the tarp must be tightly sealed around the top perimeter of the concrete storage tank by first laying down a sheet of plastic fitting, then two rubber strips which grip the tarp - see Figure 6 (Zhang and Gaakeer, 1998). Inflatable plastic domes are not common with earthen basins because installation is more difficult. The cover includes an air delivery system (a low pressure blower and variable speed fan controller) and pressure control system (a mechanical damper by which a bypass opening can be adjusted so the cover is inflated at a constant operating pressure) - see Figure 7 (Zhang and Gaakeer, 1998).

A grid of ropes is fastened across the top of the tank to prevent the cover from falling into the manure when the blower is deactivated for agitation and pumping, or when the power is off. The cover will remain inflated for an hour after the blower is turned off to allow for back-up power (Zhang and Gaakeer, 1998). These higher domes prevent snow

Figure 5 An Inflatable cover on the top of a 23 m diameter concrete manure storage tank (Zhang and Gaakeer, 1998)

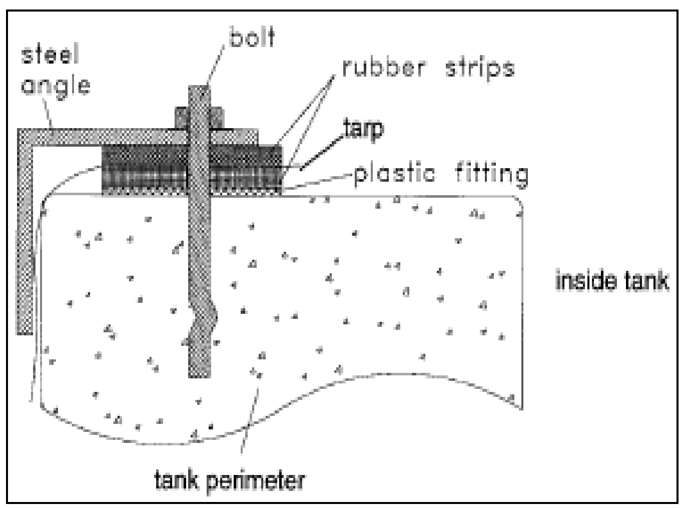

Figure 6 The attachment of the tarp to the perimeter of a concrete tank (Zhang and Gaakeer, 1998)

accumulation but wind resistance increases. Zhang and Gaakeer (1998) found that air leakage was minimal and equivalent to a typical bathroom exhaust fan. Provision to collect and treat biogas can be made through the installation of perforated pipes and an exhaust fan, to direct the gas to a biofilter or some other air treatment system before it is discharged to the atmosphere.

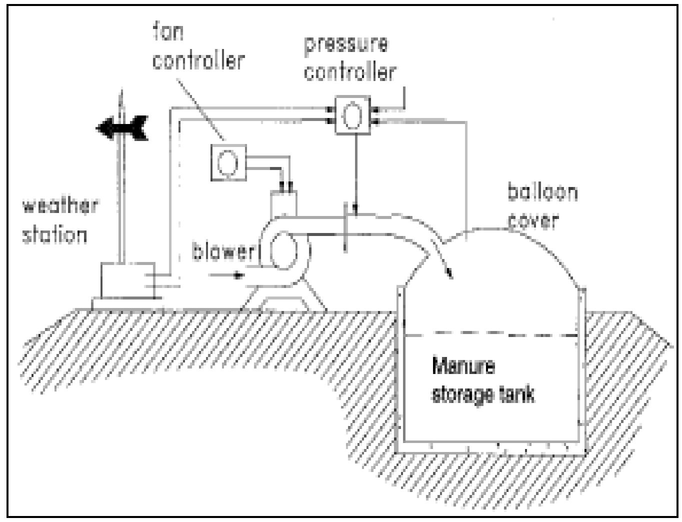

Figure 7 A sketch of the storage tank cover and the control systems (Zhang and Gaakeer, 1998)

An inflatable plastic cover is 95% effective at reducing odours, hydrogen sulfide, and ammonia concentrations (Nicolai et al., 2002). The cover has a life expectancy of 10 years and costs US$5.80 to 12.50 /m^2 (Nicolai et al., 2002). Zhang and Gaakeer (1998) estimated the cost to be US$15 /m^2 plus US$16/month for electricity to run the blower fan.

Inflatable covers appear to have gone out of favour on several Ontario livestock farms in the last few years due to problems with high winds, especially associated with power outages (Bradshaw, 2006; Hilborn, 2006).

b) Floating Plastic (negatively pressurized) - The opposite to the positively pressurized plastic cover is the negatively pressurized cover. This cover is a flexible, reinforced, high density polyethylene (HDPE) membrane. Unlike the inflatable cover, this floating cover can be installed in both concrete and earthen storages (Funk et al., 2004). For earthen basins, the cover is either fastened using anchor trenches or tethered with ropes to metal or wooden stakes located around the perimeter, as shown in Figure 8 (Bicudo et al., 2003). Blowers, connected to a ducting system, draw the air out from under the cover, creating a vacuum - see Figure 9 (Hodgkinson, 2003). This gas can also be directed to a biofilter before being discharged into the atmosphere, as shown in Figure 10. Precipitation

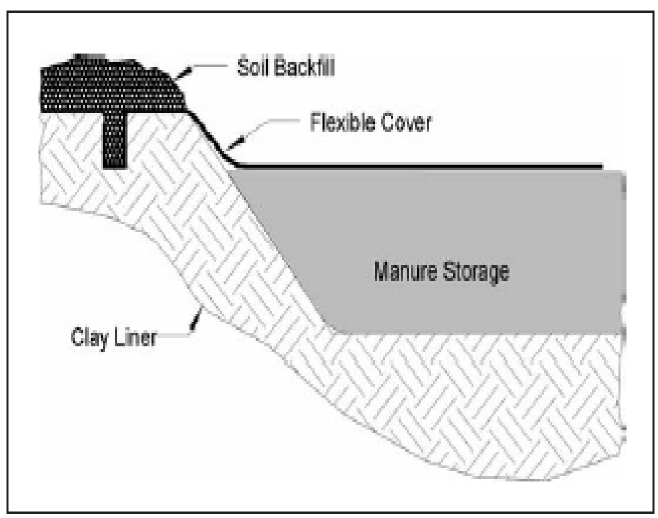

Figure 8 Fastening a cover to a berm using anchor trenches (Nicolai et al., 2002)

collected on the cover can be drained through a series of perforated collection pipes laid on the surface, which are connected to an activated pumping system (Bicudo et al., 2003).

Hodgkinson (2003) found that the cover reduced ammonia and greenhouse gas emissions. In one installation on a 30 by 40 m earthen basin, a 0.41 mm thick plastic cover cost US$7,800 installed, and US$36 per month for operating costs (Funk et al., 2004).

Figure 9 This blower is connected to a ducting system so the cover remains tight on the manure surface (Hodgkinson, 2003)

Barry (2006) studied a negatively pressurized floating cover on a concrete tank in Guelph, Ontario. Perforated pipe was laid around the perimeter of the storage under the cover and was connected to small exhaust fans. The fans drew out air to create a negative air pressure that held the airtight barrier in place. Gas bubbles emitted from the manure formed under the cover and eventually worked their way to the edge of the storage and were picked up by the fan and ducting system. An agitation system using compressed air was installed on the floor of the storage (Barry, 2006).

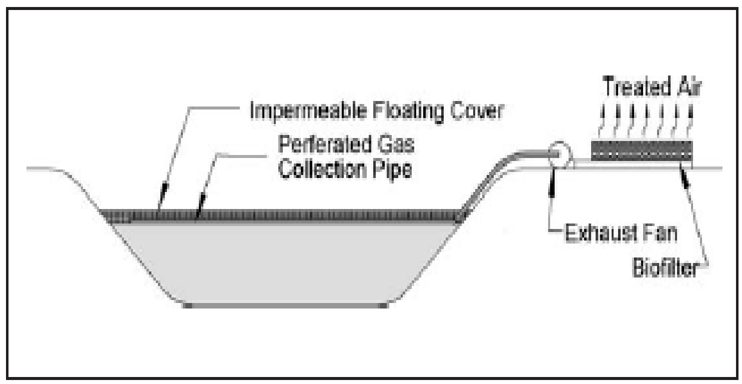

Figure 10 A system to remove and treat biogas from a manure storage using an impermeable cover and biofilter (Nicolai et al., 2002)

Precautions are recommended for the winter season to prevent the cover from tearing. During the late fall months in this study, sump pumps were used regularly to remove as much rainwater as possible on top of the cover, to minimize ice formation over winter - see Figure 11. During the winter, manure at the perimeter of the tank was agitated using a small electric air compressor, in the hopes of softening the ice so that fresh manure could be safely added to the storage. This technique proved to be ineffective. Barry (2006) suggested that, unless a better system can be developed, the precautions required to prevent tearing of the cover during the winter season seem too restrictive for widespread use of the cover design. The expected life of the cover is about 7 years (Barry, 2006).

Wagner-Riddle (2004) compared the methane emissions from two liquid swine manure concrete storage tanks, one covered with a negatively pressurized membrane and the other, an uncovered tank. The methane flux from the covered and uncovered tanks were not significantly different, except during early winter when emissions were slightly higher for the uncovered tank (Wagner-Riddle, 2004).

Figure 11 The negative air pressure cover during manure agitation by forced air in early winter (Barry, 2006)

c) Floating Plastic - Another alternative to the negatively pressurized floating cover is a floating cover that simply lays on the manure surface. This cover is anchored in the same way as the negatively pressurized floating cover but no fan is required. The gases are vented out through the sides to prevent build-up of excess pressure (Nicolai et al., 2002). Precipitation collected in the cover can be drained through a series of perforated collection pipes laid on the surface, connected to an activated pumping system (Bicudo et al., 2003). Styrofoam floats can also be sewn into pockets around the edges (Clanton et al., 1999).

Floating plastic reduced odour by 60 to 78% and hydrogen sulfide by 90% (Nicolai et al., 2002). Hornig et al. (1999) glued two 2 mm thick polyethylene film layers together and found that the cover decreased ammonia emissions by 99%. These covers are expected to last about 10 years and cost US$2.50 to $4 /m^2 (Nicolai et al., 2002).

The problem with floating plastic covers is that they are difficult to use when the manure level fluctuates during the year. Enough material is needed so that when the tank is low, the cover can still float on the manure surface, but when the tank is full, the excess tarp along the edges will bunch up (Zhang and Gaakeer, 1998). This could create problems with agitation or pumping. Disposal of plastic material after it is no longer usable can also be costly (Nicolai et al., 2002).

d) Suspended Plastic - A type of cover that is popular in northern of Europe consists of a solid vertical support post in the centre of a circular concrete tank, strips of material from the support to the walls and a plastic cover laid on top and stretched tight to the walls, as shown in Figure 12. This cover excludes all precipitation, reduces ammonia losses and reduces odour emissions (Holm-Nielsen, 2006). An access panel can be removed to allow for pump installation during agitation and spreading. No costing information is available for this report.

e) Concrete - Concrete lids are very reliable and capture 95% of odours, but are capital intensive (Nicolai et al., 2002). For example, a 30 m diameter concrete lid, 20 cm thick, is estimated to cost as much as CDN$76,000 (i.e. CDN$108/m^2) (Johnson, 2006). Concrete lids can have a life expectancy of 30 to 50 years if the lid is well designed (Johnson, 2006). Poorly designed concrete lids can lead to too much deflection or sagging in the centre of the lid, causing cracks that allow ammonia to corrode the reinforcing steel quickly. Concrete lids have been commonly used over the years on concrete tanks in Ontario and many have been in place over 30 years.

Figure 12 Plastic cover supported by central pillar and series of guy ropes

e) Wood/Steel - Wood or steel lids are also reliable but capital-intensive. A steel or wooden lid is estimated to cost US$20,000 for a 23 m diameter concrete manure tank (i.e. US$48/$m^2$) (Zhang and Gaakeer, 1998). Wooden lids are 95% effective at reducing odours and gases and have a life expectancy of 10 to 15 years (Nicolai et al., 2002). Steel lids are not commonly used because the high concentrations of ammonia cause the steel to corrode rapidly unless careful consideration is taken to ventilate the storage area or coat the steel (Johnson, 2006).

General Discussion

Tables 1, 2, and 3 summarize much of the information discussed in this report. Table 1 documents, for each type of cover, the effectiveness at reducing odour and gas emissions, typical life expectancy and capital cost. Table 2 summarizes the main advantages and disadvantages of each type of cover. Table 3 lists common manure storage covers considered by livestock producers in southern Ontario and compares them using the most important performance indicators considered by the farmers, including: ability to reduce odour and gas emissions, ability to exclude precipitation, amount of labour involved, ease of agitation, life expectancy and cost.

Table 1 -Types of covers, effectiveness, life expectancy, and capital costs.

Material	Reduction Effectiveness (%)			Life Expectancy	Capital Cost (US$/$m^2$)
	Odour	H_2S	NH_3		
Permeable Covers					
Straw	40 to 90 [a]	80 to 95 [a, b]	25 to 85 [a]	< 6 months [a]	0.2 to 0.8 [a]
Geotextile	40 to 65 [a]	30 to 90 [a]	0 to 45 [a, c]	3 to 5 years [a]	1 to 2.4 [a, c]
Geotextile/straw	50 to 80 [a]	60 to 98 [a]	8 to 85 [a]	N/A	1.3 to 2.2 [a]
Leca®	90 [a]	N/A	65 to 95 [a]	10 years [a]	13 [a]
Macrolite®	60 [a]	64 to 84 [a]	N/A	10 years [a]	13 [a]
Perlite	30 to 93 [d]	N/A	63 to 91 [d]	10 years [d]	1.3 to 2 [d]
Rigid Foam	70 to 82 [e]	N/A	N/A	10 to 20 years [e]	N/A
Oil	0 [d]	N/A	85 [d]	N/A	N/A
Natural crust	10 to 90 [b]	10 to 90 [b]	10 to 90 [b]	2 to 4 months [b]	0 [b]
Impermeable Covers					
Inflatable plastic	95 [a]	95 [a]	95 [a]	10 years [a]	5.8 to15 [a, f]
Floating plastic (neg. pressure)	95 [b]	95 [b]	95 [b]	5 to 10 years [b]	N/A
Floating plastic	60 to 95 [a, b]	90 to 95 [a, b]	95 [b]	10 years [a]	2.5 to 4 [a]
Concrete lid	95 [a]	N/A	N/A	30 to 50 years [g]	(CDN) 108 [g]
Wood/Steel lid	95 [a]	N/A	95 [a]	10 to15 years [a]	48 [f]

[a] (Nicolai et al., 2002)
[b] (Bicudo et al., 2003)
[c] (Bicudo et al., 2004)
[d] (Hornig et al., 1999)
[e] (Miner et al., 2003)
[f] (Zhang and Gaakeer, 1998)
[g] (Johnson, 2006)

Table 2 - Summary of advantages and disadvantages of various manure storage covers

Type of Cover	Advantages	Disadvantages
Permeable Covers		
Straw	- very low cost - effective odour and gas reduction	- very short lifetime - requires a manure pump that can chop straw - difficult to spread evenly and measure thickness - deteriorates with intense rainfall and wind
Straw and Oil	- low cost - stays afloat longer than straw alone - effective odour and gas reduction	- short lifetime - requires a manure pump that can chop straw - difficult to spread evenly and measure thickness
Geotextile	- low cost - relatively effective odour and gas reduction - resistant to rot, moisture, and chemical attack	- short lifetime - effectiveness at reducing odour and gases decreases over time - disposal is costly - can be submerged (e.g. intense rainfall, snow melt) - safety an issue during agitation and pumping
Clay Balls	- effective odour and gas reduction - relatively long lifetime	- when they sink, they form clumps and can plug the pumping equipment - relatively expensive
Perlite	- low cost - relatively effective odour and gas reduction - floats quickly to surface after application, compared to straw - relatively long lifetime	- relatively little performance information available - effectiveness varies significantly

Rigid Foam	- relatively low cost - relatively effective odour and gas reduction - survives intense storms - long lifetime	- complicated installation - good electrical insulator - may cause sparks - can be ignited, producing poisonous gases
Oil	- low cost	- short lifetime - produces a distinctive offensive odour
Natural Crust	- no cost	- very short lifetime - does not always form (especially on swine manure) - poor odour and gas reduction
Cornstalks, Sawdust, Wood Shavings, Rice Hulls, Ground Corncobs, Grass Clippings	- low cost	- very short lifetime - poor odour and gas reduction
Impermeable Covers		
Inflatable Plastic (positive pressure)	- long lifetime - tarp never touches manure - very effective odour and gas reduction with biofilter - prevents precipitation accumulation on top and in manure storage	- high cost - more wind resistance - must be deactivated to pump or agitate - not appropriate for earthen basins
Floating Plastic (negative pressure)	- relatively long lifetime - very effective odour and gas reduction with biofilter - prevents precipitation accumulation in manure storage	- relatively high cost - collects precipitation - bunches up when manure level fluctuates - potential for damage due to ice

Floating Plastic	- long lifetime - relatively effective odour and gas reduction with biofilter - prevents precipitation accumulation in manure storage	- relatively high cost - gas bubbles in cover - potential for wind damage - collects precipitation - bunches up when manure level fluctuates
Suspended Plastic	- effective odour and gas reduction - prevents precipitation accumulation in manure storage	- no cost information available - may not be available in North America
Concrete	- very long lifetime - very effective odour and gas reduction - very low maintenance - prevents precipitation accumulation in manure storage	- very high cost
Wood/Steel	- long lifetime - very effective odour and gas reduction - low maintenance - prevents precipitation accumulation in manure storage	- very high cost

Table 3 - Comparison of the common liquid manure storage covers considered by livestock producers in southern Ontario

	Straw	Geotextile	Inflatable Plastic	Floating Plastic (negative pressure)	Floating Plastic	Concrete
Odour Control	poor	very poor	good	good	good	very good
Reduced Gas Emissions	good	poor	very good	very good	good	very good
Excludes Precipitation	no	no	yes	yes	yes	yes
Labour/ Maintenance	very high	high	low	medium	medium	very low
Ease of Agitation	easy	hard	easy	hard	hard	very easy
Life Expectancy	< 6 months	< 5 years	< 10 years	<10 years	<10 years	>30 years
Cost	low	medium	medium	high	high	very high

Future Research Needed

The majority of research on liquid manure storage covers has involved earthen basins and the main manure type has been swine manure. Less information is available on concrete tanks and on cattle manure. More research is needed especially in the area of covers for concrete tanks (a very common storage option in many areas).

Impermeable covers offer the opportunity for collecting and using methane gas for firing water boilers for barn, shop, or home heating needs, an on-farm incinerator, or simply flaring the gas (MacLeod, 2006). A more advanced methane treatment option is the production of electricity using a methane-fired engine and matched power generation unit. Increased on-farm income through energy generation and the sale of greenhouse gas emission reduction credits are becoming a feasible option through the advancement of manure storage cover technology (MacLeod, 2006). No research results could be found where an attempt had been made to cash in on the trapped methane gas.

In summary, more research on covers for concrete tanks and energy generation from methane emitted from manure storage basins is needed.

References

Barry, D. 2006. *Experience with the Negative Air Pressure Cover at Arkell Research Station*. Canadian Pork Council, University of Guelph.

Berg, W., Brunsch, R., and Pazsiczki, I. 2006. Greenhouse Gas Emmisions from Covered Slurry Compared with Uncovered during Storage. *Agriculture, Ecosystems and Environment*, 112:129-134.

Bicudo, J.R., Clanton, C.J., Schmidt, D.R., Powers, W., Jacobson, L.D., and Tengman, C.L. 2004. Geotextile Covers to Reduce Odor and Gas Emissions from Swine Manure Storage Ponds. *Applied Engineering in Agriculture*, 20(1):65-75.

Bicudo, J.R., Schmidt, D.R., and Jacobson, L.D. 2003. *Using Covers to Minimize Odor and Gas Emissions from Manure Storages*. Cooperative Extension Service, University of Kentucky.

Bradshaw, S. 2006. Personal communication. Sam Bradshaw, Ontario Pork, Guelph, Ontario

Clanton, C.J., Schmidt, D.R., Jacobson, L.D., Nicolai, R.E., Gooderich, P.R, and Janni, K.A. 1999. Swine Manure Storage Covers for Odour Control. *Applied Engineering in Agriculture*, 15(5):567-572.

Clanton, C.J., Schmidt, D.R., Nicolai, R.E., Jacobson, L.D., Gooderich, P.R., Janni, K.A., and Bicudo, J.R. 2001. Geotextile Fabric-Straw Manure Storage Covers for Odor, Hydrogen Sulfide, and Ammonia Control. *Applied Engineering in Agriculture*, 17(6):849-858.

DeVries, H., Stevenson, R., Hayes, R., Turnbull, J.E., and Clayton, R.E. 1980. *Experiences with Floating Covers for Manure Storages*. Presented at the 1980 CSAE-SCGR 60^{th} Annual AIC Conference, Paper No. 80-218. ASAE, University of Alberta, Edmonton, AB.

Farm Safety Association. 2002. *Manure Gas Dangers*. Agriculture and Agri-food Canada, Guelph, ON.

Funk, T., Zhang, Y., Mutlu, A., and Ellis, M. 2004. *A Synthetic Earthen Lagoon Cover to Reduce Odor Emission*. Swine Odor Waste Management, University of Illinois.

Hilborn, D. 2006. Personal communication. Don Hilborn, Ontario Ministry of Agriculture, Food and Rural Affairs, Woodstock, Ontario.

Hodgkinson, D. 2003. *Negative Air Pressure Cover for Manure Storage Basins*. Greenhouse Gas Opportunities for Manure Management. DGH Engineering Ltd., Calgary, Alberta.

Holm-Nielsen, J. B. 2006. Personal communication. Jens Bo Holm-Nielsen, Head of Bioenergy Department, Centre of Ind. Biotechnology and Bioenergy, Aalborg University & University of Southern Denmark

Hornig, G., Turk, M., and Wanka, U. 1999. Slurry Covers to Reduce Ammonia Emission and Odour Nuisance. *Journal of Agriculture Engineering Research*, 73:151-157.

Johnson, J. 2006. Personal communication. John Johnson, Ontario Ministry of Agriculture, Food and Rural Affairs, London, Ontario.

MacLeod, C. 2006. *Benefits of a Manure Storage Cover*. Canadian Pork Council.

Miner, J.R., Humenik, F.J., Rice, J.M., Rashash, D.M.C., Williams, C.M., Robarge, W., Harris, D.B., and Sheffield, R. 2003. Evaluation of a Permeable, 5cm Thick, Polyethylene Foam Lagoon Cover. *Transactions of the ASAE,* 46(5):1421-1426.

Nicolai, R., Pohl, S., and Schmidt, D. 2002. *Covers for Manure Storage Units*. South Dakota State University.

OMAFRA. 2005. *Nutrient Management Act*. Retrieved from <http://www.omafra.gov.on.ca/english/engineer/facts/05-039.htm> on July 13, 2006.

Sommer, S.G., Petersen, S.O., and Sogaard, H.T. 2000. Atmospheric Pollutants and Trace Gases: Greenhouse Gas Emission from Stored Livestock Slurry. *Journal of Environmental Quality*, 29(3):744-751.

Wagner-Riddle, C. 2004. *Comparison of Methane Emissions from Covered and Non-covered Liquid Swine Manure Storage Tanks*. Canadian Pork Council, University of Guelph.

Xue, S.K., Chen, S., and Hermanson, R.E. 1999. Wheat Straw Cover for Reducing Ammonia and Hydrogen Sulfide Emissions from Dairy Manure Storage. *Transactions of the ASAE*, 42(4):1095-1101.

Zhang, Y. and Gaakeer, W. 1998. An Inflatable Cover for a Concrete Manure Storage in a Swine Facility. *Applied Engineering in Agriculture*, 14(5):557-561.