Alternative Systems

for

Piggery Effluent Treatment

a report prepared for the

Environment Protection Agency

and the

Rural City of Murray Bridge

by

FSA Environmental, Queensland

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ALTERNATIVE SYSTEMS

FOR

PIGGERY EFFLUENT TREATMENT

REPORT PREPARED FOR:

ENVIRONMENT PROTECTION AGENCY (SOUTH AUSTRALIA)

AND

THE RURAL CITY OF MURRAY BRIDGE

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EXECUTIVE SUMMARY

Background

FSA Environmental was commissioned by the Environment Protection Agency (SA) and the Rural City of Murray Bridge to prepare a report on alternative effluent systems that are available that would reduce the odour impact from piggeries. Specifically the report needed to give an estimation of the economic impact of the systems, including the extra costs involved and an indication of what size the systems may prove to be economically viable. In particular, it should address the following points.

- What technologies exist world-wide to treat high BOD wastewater containing suspended solids and pathogens?
- Which of these technologies might be applicable for use in the treatment of piggery effluent in South Australia?
- What order of magnitude size of piggery would be required in order to make suitable technologies economically viable?
- Are there other processes that could be used with each of the suitable technologies that might improve their economic viability (e.g. cogeneration of power, cogeneration of heat, production of compost / fertiliser, reuse of water as process water or for crop irrigation)?

Characteristics of Pig Manure

Manure comprises both urine and faeces. It consists of water (90% of manure), complex carbohydrates and nutrients. Complex carbohydrates consist mainly of carbon, hydrogen and oxygen. These are broken down into simpler compounds such as carbon dioxide and water during effluent treatment. Pig manure also contains large quantities of nitrogen, phosphorus and potassium, as well as minor nutrients, trace elements and salts. A range of pathogens is also contained in pig manure.

Objectives of Piggery Effluent Treatment

The objective of a piggery effluent treatment system is to treat and / or otherwise use the manure in an ecologically sustainable manner.

Generally, effluent treatment should remove organic matter, since high levels of organic matter in watercourses have a detrimental effect on water quality. Microorganisms break down organic matter.

In most cases, another objective of piggery effluent treatment is to sustainably add nutrients to the soil. Application of salts to land must also be carefully managed to avoid the types of salinity problems that are common in southern inland Australia.

Waste Minimisation

Minimisation of wastes should be a precursor to effluent treatment. Areas providing potential for waste minimisation at piggeries include minimising feed wastage,

improving feed digestibility, matching dietary formulations more closely to animal requirements (for optimal pig performance), only adding salt to diets if needed and reducing clean water use. The possibilities for adopting these strategies should be explored on a case-by case basis.

Effluent Treatment Options

Figure 1 shows the various options available for effluent treatment at a piggery. A treatment system for a specific piggery can be configured using the components in Figure 1. The configuration chosen would depend on climatic conditions, local environmental issues, economic factors and practical issues.

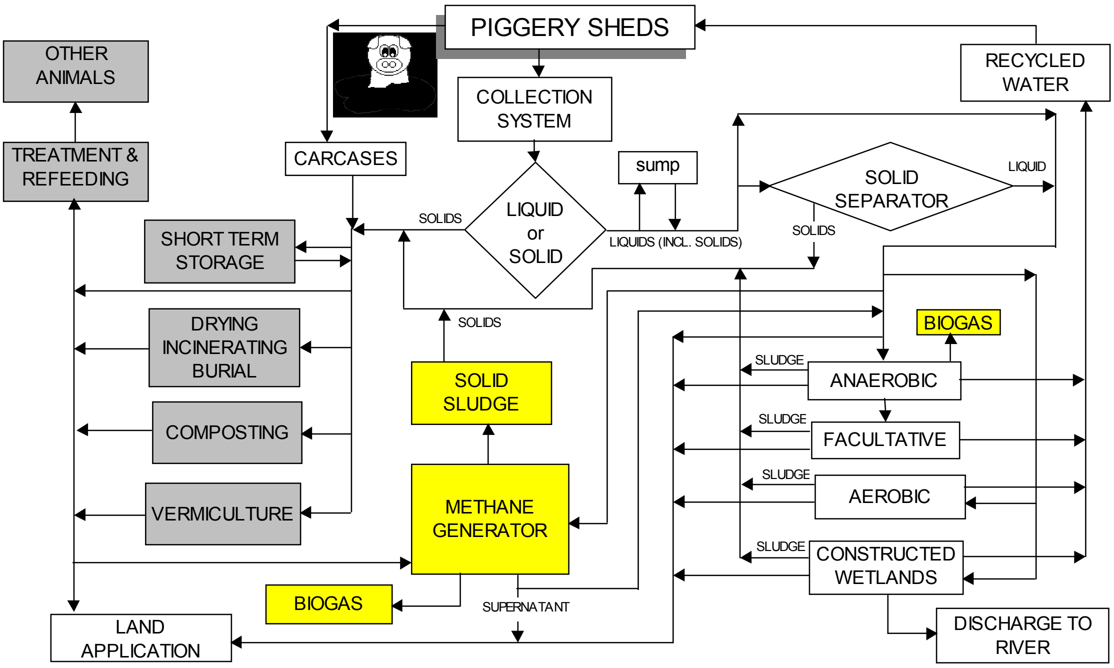


FIGURE 1 – EFFLUENT TREATMENT OPTIONS FOR PIGGERIES

Removal of Effluent from Sheds

Most Australian piggeries use either flushing channels or pits to remove effluent from sheds. There are a few pull-plug systems. Flushing systems are recommended since they encourage regular cleaning and therefore reduced odour. Static pits and pull plug systems reduce water usage. However, pit methods also release more odour and ammonia into the sheds as effluent stored in the pits is anaerobically decomposed.

Removing Solids from Effluent Streams

Removing solids from effluent reduces the organic matter load for treatment by the anaerobic pond. This allows for the pond capacity to be reduced while still complying with design standards. Providing the removed solids are well managed, this should substantially reduce odour.

Screens are a simple and low cost method for removing solids from effluent. Run-down screens and vibrating screens remove more solids than rotating screens. TS removal rates are about 10-35% for run-down screens 20-27% for vibrating screens and 4-14% TS for rotating screens. However, vibrating and rotating screens produce drier solids than run-down screens - 12-21% TS for vibrating screens, 12-17% TS for rotating screens and 6-10% TS for run-down screens. Run-down screens are the cheapest option. However, because vibrating screens produce drier, more manageable solids, these may be preferred.

Press screws can generally remove 55-80% of TS from piggery effluent streams. Finer screens remove more solids. Press screws are less efficient if the effluent stream has an inconsistent or low TS content. The solids removed by presses typically contain 20-30% TS. Belt presses probably have similar performance to press screws. Presses are more expensive than screens, but are inexpensive relative to most of the other solids separation technologies.

Horizontal centrifuges remove about 35-45% of TS from piggery effluent streams. The TS content of the solids removed is typically 20-35%. Higher TS removal rates are associated with more concentrated effluent.

A tangential flow separator (TFS) is a sophisticated device that uses lime and polymer dosing and tangential flow to remove solids. It has very high capital, operating and maintenance costs. TFS can remove about 34% of TS and at least 90% of phosphorus. The separated solids have a TS content ranging from about 6-40%.

Settling can remove more solids than most alternatives, but requires more management. There is potential for significant odours if settling basins are not regularly cleaned. For this reason, concreted trafficable sedimentation basins, or batch-operated sedimentation tanks, are recommended. About 75% of the VS in effluent may be settled within 10 minutes. This can be increased to 80% of VS with the addition of lime. SEP's also show good potential, however these need to be proven in a range of Australian conditions.

Coagulation and flocculation can be used in conjunction with other technologies to enhance solids and particularly nutrient removal. Organic polymers, metal salts and lime work are widely used for sewage treatment.

Lagoon Treatment and Other Liquid Systems

Most Australian piggeries use anaerobic ponds to treat effluent. This is a simple and inexpensive option. Properly designed and managed anaerobic ponds produce little odour. For the Murray Bridge area, the VS loading rate to the treatment volume of an anaerobic pond should not exceed 73 g VS/m^3/d. A further 25-40% of pond volume should be provided for sludge storage. The composition and inflow rate of effluent to anaerobic lagoons should be kept fairly even. This can be achieved by daily flushing of effluent channels. Anaerobic ponds tend to malfunction when the organic matter loading rate is too high, or when heavy organic loads are added infrequently. Malfunctioning anaerobic ponds produce offensive odours. In addition, removal of sludge from these ponds can release offensive odours.

Facultative lagoons are often used as secondary treatment ponds in conjunction with anaerobic ponds. A faculative pond has an aerobic layer over an anaerobic layer.

Australia's "facultative" lagoons rarely have sufficient surface area to behave facultatively and are generally anaerobic. Building larger ponds is rarely practical. This can be resolved by placing aerators on the lagoons and creating a stratified lagoon. Stratified lagoons are anaerobic ponds with shallow mechanical aerators installed to aerate the surface of the lagoon. Aeration is a proven odour control technology. However, it has high operating costs.

Aerated lagoons are sometimes used in conjunction with anaerobic and/or facultative lagoons to provide further polishing of effluent. Naturally aerated lagoons are less than 1.5 m deep to promote light penetration and oxygen transfer. The surface area of these ponds must be very large and they are rarely practical for treating intensive livestock effluent. Mechanical aerators can be used to promote aerobic conditions. However, this is very expensive.

Evaporation basins, used in conjunction with anaerobic ponds, are a good option for effluent disposal in dry climates (e.g. Murray Bridge). They can be effective in reducing odour nuisance since they remove the need to irrigate effluent.

Although constructed wetlands have been widely used to remove nutrients from municipal sewage, their capacity to treat piggery effluent is yet to be tested in Australia. Because of the high evaporation to rainfall at Murray Bridge, the successful function of a constructed wetland for treating piggery effluent is doubtful.

Alternatives to Lagoons

Under-slat scraper systems have the potential to eliminate anaerobic lagoons altogether. Proper management of the manure removed is critical if this system is to be low odour.

Deep litter systems are an alternative to conventional piggery sheds. Straw or sawdust is used for bedding in low-cost shelters or eco-sheds. This system is proven for grower and finisher pigs. Deep litter systems produce less odour than conventional sheds. However, availability of bedding materials will be a significant limitation during drought years.

Solid By-Product Management

Solid by-products must be carefully managed to prevent creation of secondary odour sources.

Composting is a method of aerobically digesting the solids separated during effluent treatment or removed as spent bedding from ecoshelters and ecosheds. The product of the composting process is a stable soil conditioner. The aerated static pile and windrow methods are the easiest and least expensive system for piggeries. Because composting is an aerobic process, it is a low odour process. It is strongly recommended that solids removed from effluent streams, and pond sludge be immediately composted to prevent them from becoming a secondary odour source.

Vermiculture is a low-odour alternative to composting. Worms are used to decompose the solids. The management requirements and the capital, maintenance and operating costs are substantially higher than for composting

Composting of carcasses within hay bale bays is becoming common practice in Australia. It works well and odour is minimal providing the carcasses are well-covered with sawdust or straw. Burial is also an effective method for carcass disposal. Proper coverage of carcasses minimises odours. Burning and dumping both create odours and are not recommended. Rendering is only an option for those located very close to a rendering plant.

Methane Generation

Methane produced by anaerobic ponds can be collected and used as an energy source. The major environmental benefit is that methane is no longer discharged to the atmosphere. To date there are no piggeries in Australia collecting methane from ponds. The economics of this would need to be examined very carefully. However, methane generation is being practiced using digesters. This is a very expensive and sophisticated method. Again, thorough economic analysis is needed.

Odour at Piggeries

Odour Nuisance

Odours from piggeries become an issue when they cause nuisance to neighbours or other receptors. The so-called FIDO factors of frequency, intensity, duration and offensiveness of odour impact define nuisance. The factors involved in odour nuisance are odour creation, odour emission (release), odour dispersion (source to receptor). Little can be done to change a neighbour's perception of odours. However, piggery operators have the ability to change odour creation, emission and dispersion.

Creation of Odour at Piggeries

In most cases, odours from piggeries are created by incomplete anaerobic break-down of the organic manure in manure, waste feed and carcasses. Anaerobic break-down occurs in the absence of free oxygen and uses microorganisms that thrive in these conditions. It is a two-stage process. In the first stage, organic matter is converted to volatile fatty acids (VFA's). In the second stages methane-forming bacteria convert these acids to methane (CH_4) and carbon-dioxide (CO_2). The methane-forming bacteria can only survive in specific environments, for instance, they have a narrow pH range in which they can survive. Hence, incomplete anaerobic digestion may occur. Odours emanate from the release of VFA's and other compounds under these circumstances.

Aerobic breakdown can occur if there is sufficient oxygen to support aerobic microoganisms. Aerobic breakdown produces more CO_2 and less CH_4 than anaerobic digestion. Generally, aerobic digestion does not produce the offensive odours associated with incomplete anaerobic break-down.

Odour Sources at Piggeries

A conventional piggery in Australia comprises sheds from which manure is regularly flushed, sometimes via a screen that removes solids, to an anaerobic treatment

lagoon. This lagoon may overtop to subsequent treatment lagoons and wet weather storages. Surplus effluent may be recycled as flushing water and / or irrigated. Australian research has demonstrated that about 80% of the odours from a conventional piggery emanate from the anaerobic effluent treatment lagoon. This suggests that the first odour reduction strategy should be through reduction or elimination of anaerobic lagoon surface area, or by encouraging aerobic digestion in the surface layer of the lagoon. Where there is incomplete digestion within an anaerobic lagoon, odour emissions are considerably higher. Primary effluent treatment lagoons emit significantly more odour than secondary effluent treatment lagoons.

Research has demonstrated that odour emissions from sheds are higher if: the temperature is warmer, the humidity is greater, pits are used rather than regular flushing, the shed is not clean or the shed is older. Diet fed, herd composition and shed stocking density may also impact upon the nature and strength of the odour. It appears that ventilation has little effect on shed odour. Deep litter sheds produce less odour than conventional sheds.

Composting of manure, separated solids and carcasses is gaining in popularity in Australia. Generally, a carbon source must be added to the solids to raise the carbon to nitrogen ratio (although removed solids may contain ample carbon), absorb water (allowing for entry of air) and to absorb odours.

Odour Minimisation

Reduction in the surface area of anaerobic lagoons, without compromising treatment standards, has very good potential for reducing odour generation. This is most easily achieved by removing solids from the effluent stream prior to it's entry to the anaerobic lagoon. It is important that the solids removed do not create a secondary odour source. Hence, these should be immediately combined with a carbon source and aerobic composted.

Dry handling of manure has good potential for significant odour reduction. Dry handling reduces or eliminates the need for treatment lagoons that are the main source of odour. Deep-litter systems have proven odour reduction potential. However, these systems have only been proven with grower and finisher pigs to date. Also, availability of bedding during drought years is a serious concern. Dry handling of manure in conventional piggery sheds also has potential but the practicalities of such a system need resolving.

Surface aeration of lagoons, theoretically, offers good potential for significant odour control. In Australia, this concept was promoted as "stratified lagoons" in the 1980's but the system was not widely adopted. As with straw covers, practical issues need to be resolved. Importantly, sufficient oxygen must be provided to the effluent.

Odour Modification

Biofilters are a proven method of odour treatment. However, while they have been shown to operate well in piggeries in Europe and North America, their applicability in Australia is limited as few sheds are mechanically ventilated.

Biofilters for lagoons (permeable, organic covers) have good potential for odour control at Australian piggeries. Experience in Canada suggests that lagoons covered with straw should emit little odour. However, the practical issues of maintaining an intact straw cover throughout the year need to be addressed. Covering lagoons with a floating organic material (such as fat from an abattoir) should be examined.

Odour Entrapment

Impermeable covers (that collect methane and odorous gases) have potential for odour reduction. The collected gas can be flared or use to generate power. However, as an odour control method only, the cost of durable, permanent lagoon covers may limit their use.

Odour Dispersion Enhancement

The effectiveness of tree barriers and other physical devices on odour dispersion are not clear.

Piggery Effluent Treatment Systems

Using the components given in Figure 1, various effluent treatment systems can be designed. The following sections describe and analyse a range of alternatives. They are designed for a 200-sow (2010 SPU) and a 2000-sow (20100 SPU) unit. The effluent treatment systems outlined include:

- Conventional systems common in Australia
- Innovative systems from Australia and overseas
- Systems proposed by Watts (1999b) specifically to reduce odour.

Fourteen different treatment system configurations were analysed. The following is a brief summary of each option.

Option 1 –Direct Land Application – Slurry Tanker

Wastes are flushed from conventional piggery sheds into a collection sump. The Manure slurry is pumped into a tanker and directly spread on agricultural land without treatment.

Option 2 – Direct Land Application – Irrigation and Composting

Wastes are flushed from conventional piggery sheds into a collection sump via a rundown screen (solid separator). A rundown screen only removes about 25% of volatile solids. The solids are composted with a bulking agent (sawdust, straw) and sold off-site as fertiliser. The liquid component is irrigated daily and without treatment onto agricultural land.

Option 3 – Anaerobic Lagoon – No separation or recycling

Wastes are flushed from conventional piggery sheds into a conventional anaerobic pond (loading rate – 80 $gVS/m^3/day$). This pond overflows into a secondary (holding)

pond from which effluent is irrigated onto agricultural land. Irrigation can be timed to match crop and weather conditions. Once in every ten years (or so), sludge is removed from the anaerobic pond, composted and sold off-site as fertiliser.

Option 4 – Anaerobic Lagoon – Solid Separation

This option is the same as Option 3 except that solids are separated from the waste stream using a rundown screen prior to entry to the anaerobic pond. This reduces the required capacity of the anaerobic pond. Solids are composted and effluent is irrigated.

Option 5 – Anaerobic Lagoon – Solid Separation and Recycling

This option is the same as Option 4 except that treated effluent is recycled from the secondary pond back through the piggery as flushing water. This reduces the requirement for clean water at the piggery, reduces the irrigation requirements and allows more frequent flushing (and thus cleaner sheds).

Option 6 – Mechanically-aerated Lagoon

Wastes are flushed from conventional sheds into a mechanically-aerated basin. No solids are removed. After treatment, the effluent flows into a storage lagoon prior to irrigation. Treated effluent is recycled as flushing water. Accumulated sludge is removed, composted and sold off-site. Mechanically-aerated treatment ponds are typical of sewage and food processing waste treatment systems. They are reliant on good management and maintenance. Problems rapidly develop if the aerators break down.

Option 7 – Covered Anaerobic Pond

This option is similar to Option 5 except that the anaerobic pond has an impermeable cover. Methane and odorous gases are collected under this cover. This biogas can be used as an energy source or simply flared (burned) off. The pond cover significantly reduces odour emissions but adds extra capital cost. The pond loading rate is increased so that pond size can be decreased thus reducing capital cost.

Option 8 – Anaerobic Digester

In this option, wastes from the piggery are anaerobically digested in a controlled system using digester tanks. Biogas is produced and this generates electricity for sale to the local grid. This system is expensive and complex but eliminates odour and has the potential to generate income from sales of electricity and fertiliser.

Option 9 – Complete Deep-litter system

In this option, conventional piggery sheds are replaced with deep-litter sheds. These sheds (known as ecoshelters) are low cost, greenhouse-type sheds in which a deep layer of litter (sawdust, straw, rice hulls) is placed. The pigs manure mixes with the litter and composts. At the end of each batch, the manure plus litter is removed and sold off-site as compost. No ponds are required. Provided that the litter remains aerobic, this is a very low odour option. However, there are pig health and growth performance issues that make this system undesirable for a full farrow-to-finish piggery.

Option 10 – Combined Anaerobic Lagoon / Deep-litter System

This option is a combination of Option 5 (for the breeding section of the piggery) and Option 9 (for the grow-out section of the piggery). The breeding herd is housed in conventional sheds and wastes are flushed into an anaerobic pond. AS the breeding herd produces about one third of the total manure at a piggery, the size of the anaerobic ponds is much smaller than a conventional system.

Option 11 – Surface-aerated Ponds

This option is the same as Option 5 except that the anaerobic pond is mechanically surface aerated. Research indicates that this should significantly reduce odour emissions but adds capital and operating costs.

Option 12 – High efficiency Solid Separation

This option is the same as Option 5 except that the rundown screen is replaced with a high-performance centrifuge solid separator. About 65% of volatile solids are removed from the waste stream. Hence, the size of the anaerobic pond is reduced. However, this adds significant capital and operating costs.

Option 13 – Anaerobic Lagoon plus Evaporation Pond

In this option, wastes are flushed into an anaerobic pond (without solid separation). Treated effluent overflows from the anaerobic pond into an evaporation pond. There is no effluent irrigation and no composting of screened solids. Occasionally sludge is removed. The size of the evaporation pond is dependent on the local climate but a large surface area is needed. A large surface area means a large odour-emitting surface. This system has very little daily operational requirements and is therefore attractive to pig producers.

Option 14 – Integrated Floc-based Sequence Batch Reactor

This is an experimental system being tested at a NSW piggery. Wastes are treated in a digester tank that is periodically aerated and non-aerated. This sequencing of each batch of effluent results in BOD and nitrogen removal. This is a technically complex system.

Comparison of Effluent Treatment Options

The performance of each option was compared via a number of key indicators. These are:

- Fresh Water Use

The use of recycling reduces fresh water requirements by about one third (assuming the same flushing requirement). Option 13 (no recycling but low flushing volume) uses about the same fresh water as systems using large flushing volumes and recycling.

- Total pond capacity (anaerobic plus secondary)

The largest total pond capacity is Option 13. This is due to the size required for the evaporation pond to limit overtopping to an acceptable frequency. Some options (1, 2, 8, 9) have no ponds (with a subsequent reduction in odour emission).

- Annual irrigation

The largest amount of on-farm irrigation occurs for options where recycling of treated effluent does not occur.

- Irrigation area required

By far, the largest on-farm irrigation areas required are Options 1 and 2. In these cases, most of the nutrients is applied to land on-site. Hence, large areas are required to achieve environmental sustainability. This is probably the reason why these options would not be suitable for a large piggery. For the 2000-sow unit, over 1000 ha (2500 ac) of good agricultural land is required adjacent to the piggery.

- Off-site compost sales

The largest amounts of off-site compost sales occur with Options 9 and 10. These are the systems based on deep-litter production. The limitations of these options are the ability to reliably purchase straw and the availability of off-site farms to purchase the compost.

- Odour emission

The largest odour emissions are predicted for Option 13 due to the large pond surface areas. The three options using conventional anaerobic ponds (3, 4 & 5) produce significant odour. The least odour is produced with the deep-litter systems. Options 1 and 2 apparently have little odour but the data in these figures only takes account of shed and pond emissions. Unless direct injection is used, the spreading of manure slurries under all weather conditions can result in significant odour.

- Capital cost per SPU

By far, the most costly scheme is the Berrybank-style anaerobic digester and co-generation system. This system can only be viable if the electricity generated is sold at a reasonable price. The covered anaerobic pond is the next most expensive option.

- Operating cost per SPU

As well as Berrybank, the mechanically-aerated options have high operating costs. This is due to the power requirements of the aerators as well as the labour and repairs and maintenance costs.

- Annual cost (operating plus capital) per SPU

The annual cost is the operating cost plus the amortised capital cost. Clearly, the anaerobic digester is the most expensive option.

Murray Bridge Locality

Murray Bridge is rural city located about 60 km east of Adelaide. It has a cool to warm dry climate. The mean annual rainfall is 347 mm. The rainfall pattern is winter dominant, with 60% of rain in an average year being received from May to October.

Pig production is an important component of the regional economy, with about 25% of South Australia's total pig production being located within the area.

Conclusions and Recommendations

Piggery waste treatment systems need to sustainably treat or dispose of large quantities of organic matter, nutrients and salts. There are many options for the design of a treatment system ranging from simple systems where virtually no treatment occurs to complex and costly systems that completely treat all of the waste and optimise the returns that can be achieved from that waste.

The system chosen for a particular site is dependent on:

- Local climate
- Environmental constraints
- Final utilisation site of nutrients
- Capital costs
- Operating costs
- Labour requirements
- Convenience
- Technical requirements

When assessing each of the thirteen options analysed according to the various key indicators, each option has some advantages and disadvantages. Without site-specific knowledge, there is no clear choice as to the best system. Close proximity of neighbours would result in a different optimum solution compared to a site where on-site land availability is an issue.

Odour is a particular issue in the Murray Bridge area. Hence, those options with the least odour emission are preferred. In particular, the option that combines the breeding herd in conventional sheds and the grow-out herd in deep-litter systems is attractive. However, not all producers are satisfied with the herd performance in deep-litter systems. If conventional anaerobic ponds are to be used, surface aeration may be the most cost-effective method of odour reduction but the ponds should be designed to function satisfactorily without aeration. This then caters for aerator breakdowns. Using current knowledge about pond emissions, the use of evaporation basins with large surface areas seems to produce too much odour.

1 INTRODUCTION

On 15 March 2000, FSA Environmental was commissioned by the Environment Protection Agency (SA) and the Rural City of Murray Bridge to prepare a report on alternative effluent systems that are available that would reduce the odour impact from piggeries. The report was to be completed by 31 March 2000. The time frame was later extended to 7 April 2000.

Specifically the report needed to give an estimation of the economic impact of the systems, including the extra costs involved and an indication of what size the systems may prove to be economically viable. In particular, it should address the following points.

- What technologies exist world-wide to treat high BOD wastewater containing suspended solids and pathogens?
- Which of these technologies might be applicable for use in the treatment of piggery effluent in South Australia?
- What order of magnitude size of piggery would be required in order to make suitable technologies economically viable?
- Are there other processes that could be used with each of the suitable technologies that might improve their economic viability (e.g. cogeneration of power, cogeneration of heat, production of compost / fertiliser, reuse of water as process water or for crop irrigation)?

Due to the short time scale for this project, it is not possible to individually cost different treatment options in detail. This report is based on a review and compilation of published information and its application to the South Australian situation. Clearly, time constraints limited accurate costing and determination of odour emission.

2 CHARACTERISTICS OF PIG MANURE

Manure, which comprises both urine and faeces, is the major by-product of pig production. In intensive pig production systems, this manure needs to be spread on land, or otherwise used, in an ecologically sustainable manner and in a practical and economic manner. Pig manure has the following components.

- Water
- Complex carbohydrates
- Nutrients
- Salts
- Pathogens

2.1 Water

About 90% of the manure produced by pigs is water. Water plays an important role in effluent treatment, since it is essential to keep alive the microorganisms that play a critical role in digestion.

2.2 Complex Carbohydrates (Organic Matter)

Complex carbohydrates are mainly composed of carbon (C), hydrogen (H) and oxygen (O). They include starches, sugars, proteins and fats. In effluent treatment terms, the complex carbohydrates (organic matter) can be variously measured and expressed as biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) or volatile solids (VS). Complex carbohydrates contain energy that can be released when they are broken down into simpler compounds such as CO_2 and H_20.

2.3 Nutrients

The nutrients in pig manure include the major nutrients (nitrogen, phosphorus, potassium), minor nutrients and trace elements. When excreted, nitrogen is usually in the ammonium form or organic nitrogen.

2.4 Salts

Salts mainly include Na^+, Ca^+, Mg^+, Cl^-, SO_4^- and CO_3^-. Although some salts are contained in the feed, most salt enters a piggery via its water supply. All excess salt consumed by a pig is excreted.

2.5 Pathogens

Pig manure contains a wide range of bacteria, viruses and other pathogens.

3 OBJECTIVES OF PIGGERY EFFLUENT TREATMENT

The objective of a piggery effluent treatment system is to treat and / or otherwise use the manure in an ecologically sustainable manner.

3.1 Complex Carbohydrates (Organic Matter)

The addition of organic matter to soils in Australia is usually beneficial but the addition of organic matter to waterways is always detrimental. In the past when discharge of treated effluent to rivers was allowable, it was usually required that the effluent had a BOD of less than 20 mg/L. Low BOD levels are usually required when effluent is irrigated so that biological clogging of the soil does not occur. As raw piggery effluent typically has a BOD of over 5000 mg/L, some form of BOD reduction is usually necessary.

Irrespective of the level of sophistication, BOD reduction (breakdown of organic matter) uses microorganisms (bacteria, enzymes, and fungi). There is a vast range of microorganisms that can survive in vastly different environments. A primary grouping of microorganisms is either anaerobic or aerobic. Anaerobic microorganisms thrive in conditions where there is no oxygen, while aerobic microorganisms need oxygen to survive.

As soon as manure is produced, microorganisms start the breakdown process. The breakdown process will continue in an ad-hoc manner if no specific effluent treatment system is used, or can continue in a precise and optimal manner if a sophisticated effluent treatment system is used. Uncontrolled breakdown occurs in manure slurries. Simple anaerobic lagoons provide the next level of treatment where 60% to 90% of BOD can be removed. Complex treatment systems such as activated sludge units and sequence batch reactors can more completely breakdown BOD.

If organic matter is broken down anaerobically, the end products are mainly methane (CH_4) and carbon dioxide (CO_2) but other (sometimes odorous) gases are produced (see Section 6.3). Most treatment systems allow the gases to escape to the atmosphere. However, methane is a potential energy source and is a greenhouse gas. Methane has about 20 times the global warming potential of carbon dioxide. Treatment systems can be designed to collect the methane produced by the anaerobic breakdown of piggery effluent.

If organic matter is broken down aerobically, more CO_2 and less CH_4 is produced.

3.2 Nutrients

As with organic matter, the nutrients in pig manure are usually beneficial when applied to soil and always detrimental when added to watercourses. Hence, in most cases, the objective of piggery effluent treatment systems is to ensure that the nutrients end up in soil (where they are used as a fertiliser). Loading rates of nutrients must be matched to soil conditions and crop requirements. Excess nutrients can be leached from the soil into surface and groundwaters. Nitrogen and phosphorus are the elements of most concern.

In Europe, nitrogen causes a problem not encountered in Australia. Much of the nitrogen in raw manure is in the ammonium form. This can escape to the atmosphere as ammonia (NH_3). In many areas in Europe (the Netherlands, Germany), ammonia emissions have lead to acid rain. Hence, the control of ammonia emissions from piggeries is a major issue in Europe.

3.3 Salts

Salts can lead to degradation of watercourses and soils. It is difficult to separate the nutrients in manure from the salts. Hence, when manure is applied to soil (either as a solid or as effluent), salts are applied to soils. Excess salt applications can cause the types of salinity problems common in southern inland Australia. Depending on the ratio of sodium to calcium and magnesium, the salts may also cause soil structural problems (sodicity, surface sealing).

Monitoring data collected by FSA Environmental on anaerobic lagoons indicates that salt levels in effluent can vary from 2 dS/m to 16 dS/m. The salinity of the effluent is determined by the salinity of the incoming water supply, the amount of recycling and evaporation of effluent.

3.4 Pathogens

Pathogens in the effluent have the potential for harmful effects on humans, pigs and other livestock. However, most of these pathogens die rapidly when desiccated or exposed to sunlight. Few effluent treatment systems for piggeries specifically aim to reduce pathogens.

4 WASTE MINIMISATION

Piggery by-products may be regarded as wastes or as resources for reuse. As with any "waste disposal" problem, the first approach should be waste minimisation. There are several areas of potential waste minimisation at piggeries.

- Feed wastage minimisation

Estimates of feed wastage at piggeries vary from 5% to 20% or more. A kilogram of spilt feed is equivalent to several kilograms of manure when added to an effluent treatment system, since none of the energy, protein and nutrients in the feed has been digested. Care in reduction of feed wastage makes economic and environmental sense. Where feed is spilt in feed alleys, sweeping it up prevents it from entering the effluent treatment system.

- Feed digestibility

The selection and treatment of the energy components in the diet (grain) can change the digestibility of the diet. Increased digestibility results in decreased excretion of complex carbohydrates.

- Nutrient minimisation

Research has been undertaken in Europe and the USA to minimise the amount of nitrogen and phosphorus in pig diets and to make those nutrients more digestible. This produces equivalent pig growth, but reduced nutrients excreted.

- Salt minimisation

Apart from minimising the amount of salt added to the diet, the main method of salt reduction is to use a water source that has a low salt content and then to minimise water usage. For example, if a piggery uses 40 ML per year of bore water with a salt content of 5000 mg/L (EC=7.8 dS/m), then 200 tonnes of salt enters the piggery each year. If water use can be reduced to 30 ML (e.g. by recycling) and the water was drawn from a river with a salt content of 500 mg/L (EC = 0.8 dS/m), then annual salt intake is reduced to 15 tonnes.

- Water use reduction

Reducing the clean water usage of a piggery reduces the volume of effluent for treatment, and conserves a resource. The potential for water use reduction depends on the design of the effluent channels under the sheds and the configuration of the effluent treatment system. Solids separation equipment tends to work more effectively when effluent is more concentrated. However, reducing water usage does not reduce the quantity of organic matter for treatment. Also, if insufficient water is used for cleaning, sheds may not be cleaned effectively and odours can be generated. Anaerobic lagoons may also malfunction if they contain insufficient water, which can be a problem in dry environments. However, recycling of treated effluent as cleaning water can help to save clean water without reducing the total cleaning water volume.

5 EFFLUENT TREATMENT OPTIONS

Figure 1 shows the various options available for effluent treatment at a piggery. A treatment system for a specific piggery can be designed using the components in Figure 1. The configuration chosen would depend on climatic conditions, local environmental issues, economic factors and practical issues. Some of the components in Figure 1 need further discussion.

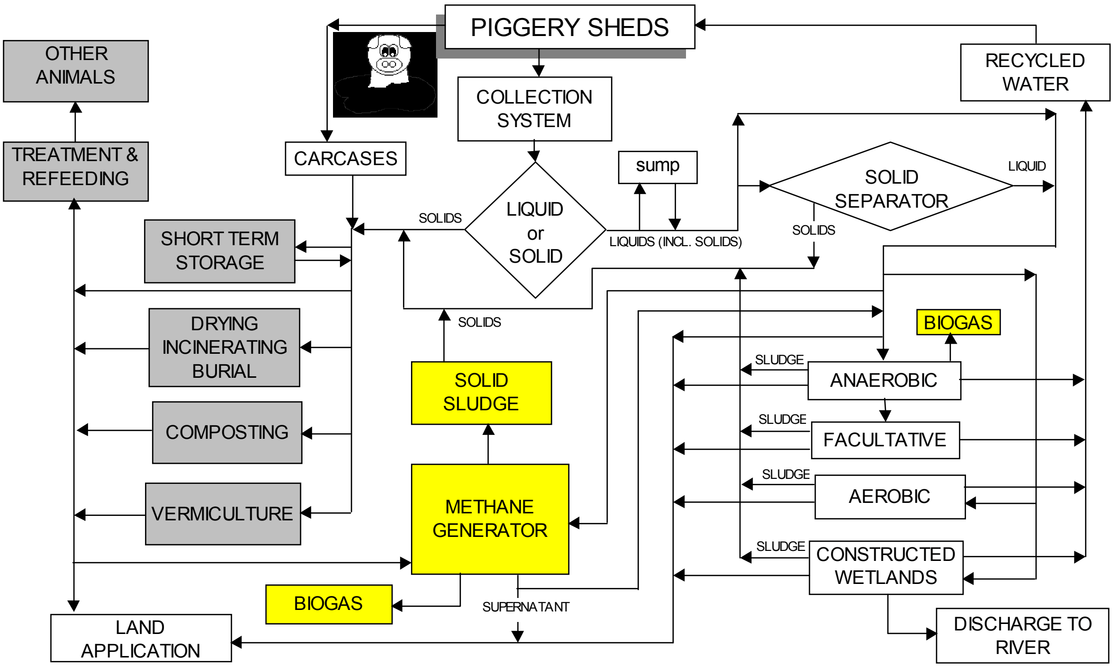


FIGURE 1 – EFFLUENT TREATMENT OPTIONS FOR PIGGERIES

5.1 Collection Systems

In a survey of Queensland piggeries, McGahan *et al*. (1996) found that about 60% of piggeries used flushing channels to remove effluent from sheds while about 25% used static pits.

From discussions with Chris Harris (Department of Environment and Heritage, pers. comm. 5 April 2000), most piggery operators in the Murray Bridge area use either flushing channels or pits. A few of the larger, newer piggeries use pull-plug systems. There are also a few ecoshelters in use.

Flushing systems comprise box or V-channels beneath the flooring of sheds. Box drains tend to be preferred since manure does not stick to the side walls. Slatted flooring allows manure and waste feed to drop, or be hosed, through the flooring and into the channels. These are cleaned by flushing with water, generally once or twice a day. The water is usually released from flushing tanks or tipping buckets (see Photograph 1). Underslat drains require a water velocity of at least 0.9 m/s, an initial flow depth of 75 mm and a flush duration of at least 10 seconds to dislodge and transport solids from the drains (Kruger *et al.* 1995). Flushing channels are the preferred method for removing manure and waste feed from sheds. They promote

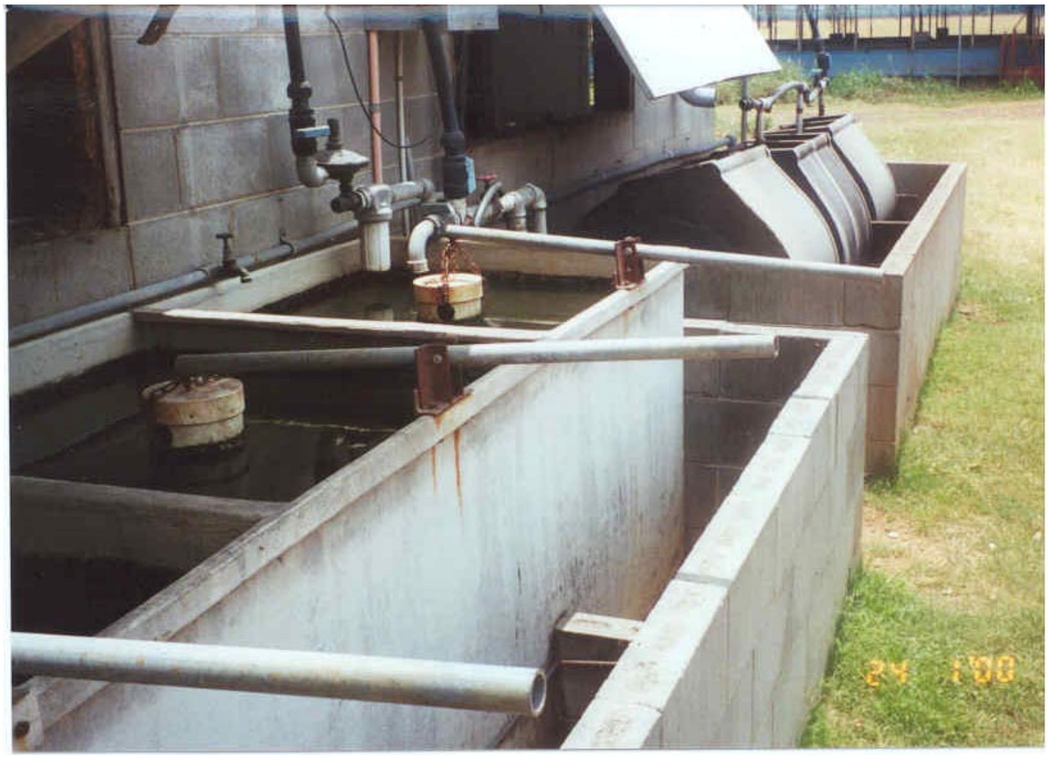
regular cleaning of channels and do not encourage anaerobic decomposition of organic matter beneath the sheds.

Static pits are an older-style method of effluent removal system. Manure, waste feed, hosing water and spilt drinking water falls through slatted flooring into pits. The effluent is stored in these pits until released, generally once every 5-10 days. This system reduces water usage. However, it releases more odour and ammonia in the sheds as the effluent decomposes anaerobically in the pits. Static pits are not a preferred effluent removal system.

Pull plug systems store effluent in small underfloor pits for up to a week. The pits are drained once a week using a central gravity release pipe. The pit is then partly refilled with clean water. The system uses less water than a conventional flushing system. It is also claimed that odour and ammonia levels are lower with this type of system. However, past problems with pit storages open this claim to doubt.

The flushed wastes can either flow directly to a treatment pond or can flow into a collection sump (see Photograph 2) from which the wastes can be pumped to a solid separator, tanker or pond.

Dry scraping and deep litter systems provide alternative methods for collecting effluent. For further detail, refer to sections 5.9 and 5.10, respectively.



PHOTOGRAPH 1 – FLUSH TANKS FOR UNDER-FLOOR FLUSHING OF SHEDS

PHOTOGRAPH 2 – MANURE COLLECTION SUMP

5.2 Solids Separation Systems

In Australia, most piggeries use lagoons to treat their effluent. The benefits of solids separation prior to lagoon treatment include:

1. Reduced organic load to the lagoon
2. Improved biological degradation in the lagoon due to removal of some of the non-biodegradable solids.
3. Reduced sludge accumulation rate due to reduced solids entering lagoon.
4. The required lagoon capacity per standard pig unit is reduced (Casey *et al.* 1995).

Because removal of solids reduces the organic load of the effluent, a smaller lagoon is needed to treat the effluent stream. A smaller lagoon surface area should reduce the odour emission rate of the lagoon.

Research by Zhang and Westerman (1997) cited by Westerman and Bicudo (1998) recommends the removal of fine particles (diameter of less than 0.25 mm) if odour generation and effluent nutrient content is to be significantly reduced. The fine particles are more readily digested and contain most of the reduced carbon compounds, nutrients and protein in the effluent stream. These compounds are the precursors for odour generation.

Based on data collected for Western Australia by Payne (1990) cited by Casey *et al.* (1995), the most common solids separation device in use is the run-down screen (see Photograph 3). A very small number of piggeries use centrifugal screens or

centrifuges. It is likely that adoption of alternative devices has been hindered by relatively high costs, maintenance requirements, labour requirements, complexity of design and operation and inferior performance.

Recently, interest in other solids separation devices has emerged. In particular, there is much interest at present in press screw separators. Various solids separation devices are discussed below.

5.2.1 Screens

Screens are usually formed from wedge-shaped bars spaced 0.05-0.15 mm apart (Fulhage & Pfost, 1993). They separate solids from liquid on the basis of particle size and shape. Screen efficiency depends upon the mesh size; the area of the screen; and the flow rate, solids percentage and fluid viscosity of the liquid to be screened (Buhp and Ginaven 1980, cited by Casey *et al.* 1995). Screens are only able to remove particles larger than the screen size. However, higher removals are possible using coagulation and flocculation prior to mechanical removal (McKenney, ND). A range of screen types is available. The performance of these is discussed below. (Coagulants and flocculants were not used in the trials outlined).

The most common screen is the stationary run-down screen (see Photograph 3 and Figure 2), sometimes called a stationary incline screen or static screen (Fulhage & Pfost 1993). The screen is installed in-line, at the start of the effluent treatment system. Effluent must usually be pumped from a sump to the top of the screen, although gravity flow may work in certain situations. The larger solids are trapped by the screen. These slide down the screen and into a storage area. The liquid and very fine particles pass through the screen where they can are directed to an anaerobic lagoon or storage (Kruger *et al.* 1995). A significant problem with run-down screens is that a biomass film rapidly develops across the surface of the screen, blinding or blocking the screen. This significantly reduces their usefulness.

A vibrating screen is similar to a run-down screen except that the liquid for separation is poured onto a rapidly vibrating screen. The solids slide to the edge of the screen, while the liquid passes through the screen. Because of the moving parts, vibrating screens have higher maintenance and power requirements than stationary run-down screen (Kruger *et al.* 1995). The vibrating helps to prevent blinding (Mukhtar *et al.* 1999; Fulhage & Pfost 1993), although regular cleaning is still needed.

PHOTOGRAPH 3 – STATIONARY RUNDOWN SCREEN AT A PIGGERY

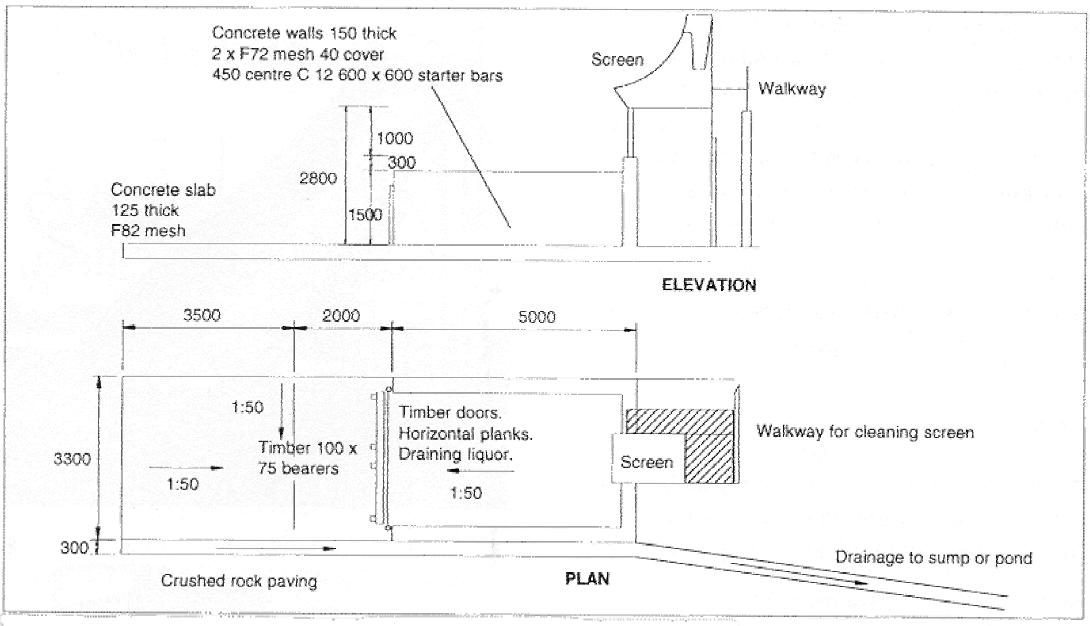


FIGURE 2– STATIC RUNDOWN SCREEN

(taken from Kruger *et al*. 1995)

An in-channel flighted conveyor screen or drag conveyor screen comprises a run-down screen and a series of flighted conveyors. The conveyors drag the liquid manure over the screen. The liquid drains through the screen and the solids are deposited on a collection pad (Fulhage & Pfost 1993; Muckhtar *et al*. 1999). Because this type of screen can be placed within an open effluent channel, the need for a

sump and pump are eliminated. However, because of their moving parts, these screens have higher operating and maintenance requirements than run-down screens (Mukhtar *et al.* 1999).

A rotating or centrifugal screen comprises a spinning cylindrical screen (see Figure 3). The liquid for treatment is applied to the inner surface of the screen, which resembles the inside of a clothes drier. The solids remain on the surface of the screen and the liquid moves through the screen (Fulhage & Pfost 1993, Zhang & Westerman 1997). A scraper can be used to remove solids collecting on the screen (Mukhtar *et al.* 1999).

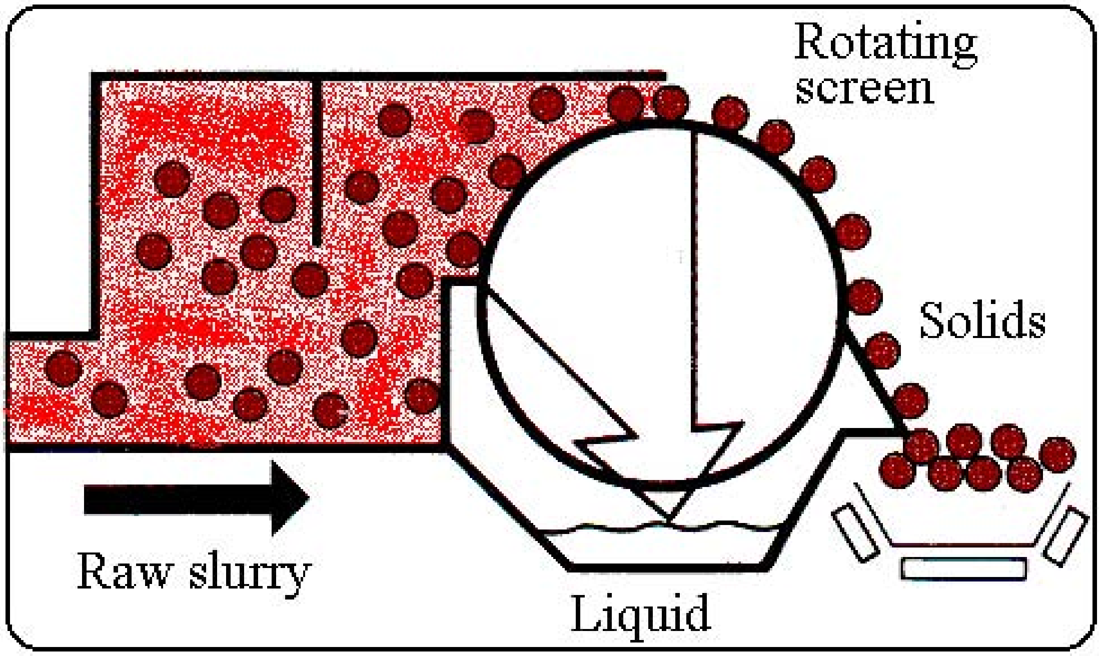


FIGURE 3 – ROTATING SCREEN

The separation efficiency of the various types of screens has been widely studied.

Shutt *et al.* (1975) (cited by Casey *et al.* 1995), compared the solids removal efficiencies of stationary run-down screens and vibrating screens with different-sized screen openings. Effluent with a total solids (TS) content of 0.2-0.7%, and a range of flow rates were used for the comparisons.

Stationary run-down screens with screen openings of 1 mm and 1.5 mm were compared using flow rates of 0.0021 m^3/s, 0.0031 m^3/s, 0.0039 m^3/s and 0.0052 m^3/s. Over all flow rates, the 1 mm screens performed significantly better than 1.5 mm run-down screens. The 1 mm screen performed best at the slowest flow rate (0.0021 m^3/s), removing 2.1% of the influent volume, 35.2% TS, 21.5% volatile solids (VS), 69.1% chemical oxygen demand (COD) and 62.2% of biological oxygen demand (BOD) (by volume). For the 1.5 mm screen, performance was optimised at 0.0039 m^3/s, where 9.8% TS and 5.3% VS (by volume) were removed. Over all speeds and both screen sizes, the TS content of the solids removed ranged from 6% to 10%.

For the vibrating screens, openings of 0.12 mm, 0.17 mm, 0.21 mm and 0.39 mm were tested with flow rates of 0.00068 m^3/s, 0.0011 m^3/s and 0.0018 m^3/s. The best

result was achieved with the largest screen size (0.39 mm) and a flow rate of 0.0011 m^3/s. This removed 0.6% of the influent volume, 22.2% TS, 28.1% VS and 16.1% BOD. The TS concentration of the solids removed was 16.4% (wet basis). For the other vibrating screen opening sizes, performance was optimised at the same flow rate.

Because screen sizes and flow rates were different for the stationary and vibrating screens, direct comparisons are difficult. However, for a given flow rate, it was concluded that stationary screens would be more effective than vibrating screens at removing solids.

Piccinini and Cortellini (1987) (cited by Casey *et al.* 1995) compared the performance of stationary run-down, rotating and vibrating screens; as well as centrifuges (covered later). The screens were tested with effluent containing 1-4.5% TS, delivered at flow rates of 0.13-0.20 m^3/s. Screen opening sizes of 1 mm, 0.8 mm and 0.44 mm were used for the rundown, rotating and vibrating screens, respectively.

The run-down screen removed 17.6% TS, 22% VS, 12.5% COD, 4.2% total Kheldahl nitrogen (TKN), 5.3% phosphorus (P) and 7.1% potassium (K). The rotating screen removed 13.8% TS, 19.3% VS, 6.7% COD, 8.4% TKN, 11.1% P and 5.9% K. The vibrating screen removed 20.9% TS, 27.8% VS, 18% COD, 3.7% TKN and 8.4% P.

The solids removed by the run-down screen had a TS content of 5.4% (wet basis), compared with 11.7% and 12.4% for the rotating and vibrating screens, respectively. The run-down screen “solids” were difficult to handle because of their high moisture content. This may partly have been due to rapid blinding of the stationary screen.

For removal of TS and VS, the vibrating screen was most effective, followed by the run-down screen and then the rotating screen. The run-down screen also removed significantly more nutrients. However, the high moisture content of the solids removed by the run-down screen was a definite disadvantage. Blinding may have contributed to the high moisture content. For this reason, the vibrating or rotating screens are most desirable, unless high nutrient removal is a target and handling ease is not important. In this case, the stationary screen was recommended.

Hegg *et al.* (1981) (cited by Casey *et al.* 1995) compared the performance of a vibrating and rotating screens.

A 0.75 mm rotating screen was tested with two sets of rotation speeds: 3.0 rpm, 4.8 rpm, 6.5 rpm and 8.6 rpm (four-speed) and 1.9 rpm, 3.0 rpm, 4.8 rpm, 6.5 rpm and 8.6 rpm (five-speed). For the four-speed test, an inflow rate of 0.0018-0.005 m^3/s and influent with a TS concentration of 2.54% was used. The TS removal rate was 4% (d.m. basis) and the COD removal was 9%. The TS concentration of the solids removed was 15.6% (w.b.). The five-speed test used an inflow rate of 0.0013-0.0039 m^3/s and influent with a TS concentration of 4.12%. It achieved a significantly higher TS removal rate of 8% and a COD removal rate of 16%. The TS concentration of the solids removed was 16.6%. This suggests that the lowest rotating speed has a very high removal rate relative to the other speeds, although the lower flow rate and higher influent total solids concentration may also have had an effect.

For the vibrating screens, screen sizes 0.635 mm, 0.83 mm and 1.574 mm were tested. The finest screen (0.635 mm) performed best. With an inflow rate of 0.0006-0.001 m^3/s and an influent TS concentration of 1.83%; the screen removed 26.9% of TS and 24% of COD. The TS concentration of the solids removed was 20.9%. The

coarsest screen (1.574 mm) worked least effectively, removing only 3% TS from influent containing 1.55% TS.

This research demonstrated that vibrating screens work significantly better than rotating screens, providing a fine screen is used. The vibrating screen removed up to 26.9% TS compared with 4-8% for the rotating screen. However, when a coarse screen was used in the vibrating screen, only 3% of solids were removed. The solids removed by the vibrating screen were also drier.

Holmberg *et al.* (1983) cited by Zhang & Westerman (1997) used a vibrating screen with five different screen sizes (8, 18, 30, 60 and 150 mesh) to determine the effect of screen size on TS removal rates for flushed pig manure. The average TS content of the influent was 3.6%, and the flow rate used was 0.15 m^3/min. The TS of the solids removed increased from 2.4% for 150 mesh screen to 17.3% for the 8 mesh screen. However, N and P removal as a percentage of TS removal increased with finer screen sizes.

Payne (1990) (cited by Casey *et al.* 1995) examined the performance of run-down screens, centrifugal screens and centrifuges (discussed later).

The run-down screens were tested at three Western Australian piggeries. The TS concentration of the influent ranged from 0.33% to 6.1% (mean 1.83%). The average removal efficiency of the screens was 20.6% TS, 23.8% VS, 8.5% BOD, 8.1% TKN and 11.1% P. However, the results varied widely depending on the influent TS concentration. It was concluded that screens are inefficient at removing nutrients and BOD since they are unable to remove the fine particles that contain most of the nutrients and organic matter.

Two centrifugal screens were tested. The screen size was 1.2 mm, the rotational speed was 1430 rpm and the mean influent TS concentration was 1.23%. For influent with a mean TS concentration of 1.23%, the screens removed 0.7% of the inflow containing 11.5% of TS, 15.4% of VS 1.1% of TKN and trace amounts of P. A positive linear relationship was established between the TS concentration of the influent and the outgoing TS mass. The low nutrient removal rate may have been because most nutrients are in fine particles (Hill and Tollner 1980, cited by Casey *et al.* 1995). The solids removed had a TS content of 21.1%.

In a laboratory experiment, Hill and Tollner (1980) (cited by Casey *et al.* 1995) examined the effect of screen sizes on solids separation rate. Sieves with screen sizes of 0.1 mm, 0.25 mm, 0.5 mm, 1 mm, 2 mm and 4 mm were compared. They also used 0.1 mm sieves to compare single and multi-screen performance. The influent used had a total solids concentration of 0.72-2.55% (mean 1.86%). The sieves were placed over columns and influent was poured through them. The research showed that finer screens remove a greater proportion of organic N as a fraction of TKN. This suggests that most of the organic matter is in the finer particles. In the comparison of single versus multiple sieves, the researchers found that the single sieve removed more TS (62% V 54%), VS (68% V 60%), COD (58% V 53%) and P (37% V 25%). N removal rates were similar for both devices (31% V 30%). It is thought that the higher removal rates for the single screen was probably due to increased blinding. However, the higher P removal by the single screen may have been due to ionic bonding of fine organic colloids.

Jett *et al.* (1974) (cited by Casey *et al.* 1995) investigated the effect of diet on particle size distribution in manure. They screened the manure to find the proportion of different nutrients and compounds in different-sized manure particles. They found

that 68% of the nitrogen-free extract (NFE) in the manure was retained by a 0.25 mm screen. NFE comprises carbohydrates and fibre and should be positively correlated with COD. If this is the case, this research is in conflict with the findings of Hill and Tollner (1980) and Payne (1990) who found that most particles contributing to COD have a diameter of less than 0.1 mm.

A number of conclusions can be drawn from the research.

Fine screens generally remove more solids, particularly VS. For run-down screens, a 1 mm screen seems to work much better than a 1.5 mm screen. However, very fine screens may hinder solids removal, probably as a result of screen blinding. For example, a 0.39 mm vibrating screen was found to be superior to screens ranging from 0.12 mm to 0.21 mm. Fine screens may also remove a greater proportion of organic matter since it appears that more organic matter is contained in very fine particles compared with coarse particles. However, some research contradicts this finding.

TS removal rates for the various screens vary widely. However, run-down screens and vibrating screens remove more solids than rotating screens.

TS removal rates for run-down screens range from 9.8% (1.5 mm screen) to 35.2% (1 mm screen), although a TS removal rate of 17.6% was reported for a 1 mm screen. Vibrating screens have been reported as removing 3% (1.574 mm screen) to 26.9% of TS (0.635 mm screen), although TS removal rates seem more consistent for 0.44 mm to 0.635 mm screens - 20.9% (0.44 mm screen) to 26.9% (0.635 mm).

Rotating screens are reported as removing 4% (0.75 mm screen) to 13.8% TS. Rotating screens remove more solids if lower rotational speeds are included in the speeds used.

Vibrating and rotating screens produce significantly drier solids than run-down screens. This has important implications for handling and management. For the vibrating screens reported above, the total solids contents of the solids removed range from 12.4% (0.8 mm screen) to 20.9% (0.625 mm screen). For rotating screens, TS concentrations of 11.7% (0.44 mm screen) to 16.6% (0.75 mm screen) are reported. For run-down screens, values of 5.4% (1 mm screen) 6-10% TS (1-1.5 mm screen) are reported. At these TS concentrations, the screenings are still a slurry, and very difficult to handle. Also, significant odour problems can occur as the wet slurry ferments.

Blinding is a significant problem with screens, particularly fine screens. It can be managed by scrubbing screens weekly with a wire brush; occasionally using high pressure washing to remove material from the back of the screen; installing sprinklers on the screen for manual washing; occasional washing with dilute boric acid (or similar) (Kruger *et al.* 1997). Fulhage & Pfost (1993) suggest installing a wash down system to prevent solids from drying and blocking the screen. Fernandes *et al.* (1987) (cited by Casey *et al.* 1995) developed a continuous belt microscreening unit. The device comprises a fine screen that is continuously cleaned. The device removed 40-60% TS from influent. The solids removed had a TS concentration of 14-18%. Details of the composition and flow rate of the device are not provided. Screens with wash down systems are available commercially in Australia (e.g. Baline separator), although these are very expensive compared with standard run-down screens.

Stationary run-down screens are considerably cheaper to purchase and operate than the more sophisticated screens or alternative separation devices (see Table 1). However, because they have good solids separation properties and produce drier solids, vibrating screens may be preferred.

5.2.2 Presses

A belt press incorporates a porous belt that is passed horizontally through rollers. The rollers press the liquids from the solids through the belt, while the solids are carried along on the belt (Fulhage & Pfost 1993). This separator is like an old-fashioned washing machine wringer. The dry matter content of solids produced by this process is 20-30% (Kruger *et al.* 1995).

In a press with a rotating screen, the slurry passes between cylindrical screens and press rollers. The liquid is pressed through the screen and the solids remain (Fulhage & Pfost, 1993). This system can handle influent with a TS content ranging from very low to 15-20%. Depending on the screen size used, the wet solids have a very high dry matter content (Kruger *et al.* 1995).

A piston press is being developed by the USDA/ARS Dairy Forage Research Centre and the University of Wisconsin. It is claimed that this device has produced solids containing 30% TS (Fulhage & Pfost, 1993).

A screw press comprises a cylindrical screen with a screw-conveyor in the centre. The conveyor presses the solids against a screen to remove moisture. The conveyor also moves the solids from one end of the press to the other to a collection area (Mukhtar *et al.,* 1999).

The roller, belt and rotating screen methods were tested with dairy effluent. The solids produced had a TS content of 11-28%, with the belt unit producing the driest solids (Fulhage & Pfost, 1993).

Purdue University is investigating the use of polymers and belt presses for increasing the bulk density and nutrient content of dairy manure. Similar technology could be applied to piggery effluent (McKenney, ND).

The researchers added aluminium sulfate to the influent as a coagulant. The influent had a TS content of 8.3%. This was dewatered to an average of 22.8% TS. However, fine particles occasionally clogged the pump. This problem was solved by using an agricultural chopper pump to deliver the influent to the belt press. This pump reduced the size of the solids in the manure and improved the suspension of the material. A modified cationic polyacrylamide was used as a coagulant. Influent containing up to 8.3% solids was dewatered to at least 20% TS. Removal rates for TS were consistently between 71% and 78%. Coagulant was added at rates of 11.4-20.5 L/hr for flow rates of 635-770 L/hr (McKenney ND).

Hahne *et al.* (1995) (cited by Westerman and Bicudo 1998) tested a screw press with a combination of three different screen-sizes, influents and flow rates. The first test used a screen size of 0.5 mm, an influent TS content of 4.5% and a liquid outflow of 2.35 m^3/hr. It removed 41.4% of TS, 11.1% of N and 21.7% of P_2O_5. The TS content of the solids removed was 24%.

The second test used a screen size of 0.75 mm, influent TS content of 4.5% and a liquid outflow of 8.9 m^3/hr. The press screw removed 64.9% of TS, 17.9% of nitrogen and 45.3% of P_2O_5. The TS content of the solids removed was 20.5%.

The third test used a screen size of 1.0 mm, influent TS of 4.5% and liquid outflow of 12.6 m^3/hr. The press screw removed 20.1% TS, 5.0% of N and 6.8% of P_2O_5. The TS content of the solids removed was 28.2%.

FAN Engineering manufacture a press screw type separator (see Photograph 4) that is attracting considerable interest in piggeries in Australia. These devices come in 10 m^3/hr, 30 m^3/hr and 100 m^3/hr capacities. Screen sizes available include 0.25 mm, 0.5 mm, 0.75 mm and 1 mm. The dryness of the solids produced is controlled by adjustable weights at the outflow end. FAN have provided research results for an evaluation of the press screw using piggery effluent. The piggery produced 20-41 m^3/hr of effluent although 2.3-8 m^3/hr by-passed the press screw leaving between 12 m^3/hr and 38.7 m^3/hr to be processed. The TS content of the influent was 4.5%. The reported total solids removal rate was 65%, with solids having a total solids content of 20-34%. FAN Engineering expects to achieve a total solids removal rate of 60%.

Yu (1992) evaluated the FAN press-screw in an on-farm trial. Screen openings of 0.5 mm and 0.75 mm were tested. A chopper pump was used to deliver piggery slurry to the separator. Samples of influent, effluent and solids were collected from each screen at four different times. The TS concentration of the influent averaged 5.5% (range 5.4-5.8%) for the 0.5 mm screen and 4.5% (range 2-5.6%) for the 0.75 mm screen.

The 0.5 mm screen removed 79.1% TS (range 73.7-85.7%), 83.7% VS (range 78.8-89.8%), 83.4% TSS (range 81.5-88.4%) and 86.2% VSS (range 83.1-90.5%). The dry matter content of the solids removed averaged 26.6% (range 25.1-27.7%).

The 0.75 mm screen removed 56.2% TS (range 22.9-71.9%), 59,8% VS (range 21.3-76.6%), 60.7% total suspended solids (TSS) (range 31.1-76.9%) and 63.1% volatile suspended solids (VSS) (range 34.3-78.1%). The dry matter content of the solids removed averaged 27% (23.4-32.2%).

Chastain *et al*. (1998) studied the performance of a FAN separator using a pig slurry that had settled for 8 t0 12 days. In part, they found that:

- The amount of TS and VS removed by the separator increased as the total solids content of the slurry increased.
- The percentage of VS removed ranged from 1% at TS_{in} = 11.1 g/L to 31.7% at TS_{in} = 70 g/L.
- The screw press removed 34.9% of the COD from swine manure regardless of TS_{in}.
- The concentrations of VS, TKN, NH4-N, organic-N, and TP in the influent and effluent were found to correlate well with the total solids content.
- The total solids content of the separated solids ranged from 22.6% to 34.4%. The separated solids piled easily and did not give off a strong odour.

This data is different from Yu (1992). However, it is clear that the performance of the separator improves if the solids content of the slurry increases.

Huber technology also manufacture a press screw type separator called the Huber-Rotomat Manure Separator. An option for this device is a reverse osmosis device to

further purify water. It is claimed that solids removed by the device have a TS content of 34-38% (Huber Technology ND).

A belt press used with coagulants is able to remove 71-78% TS from dairy cow effluent. The solids removed have a TS content of 20-22.8%.

The removal efficiency of press screw separators depends on the size of the screen fitted, the TS content of the influent and the influent delivery rate. However, the press screw is able to remove over 85% of TS and about 90% of VS from effluent streams using a 0.5 mm screen. Lower solids removal is expected with a 0.75 mm screen, although this depends on the influent delivery rate. It appears that press screws are significantly less efficient if the effluent stream has an inconsistent or low TS content. Under ideal operating conditions, average TS removal rates of 55-80% could be expected. No data for a press screw used with coagulants was available.

The dry matter content of the solids removed by presses is typically 20-30%. This means the solids are readily manageable.

PHOTOGRAPH 4 – FAN SCREW PRESS SEPARATOR

(operating on dairy wastes, Texas, USA)

5.2.3 Cyclones

Cyclones are conical devices that sit vertically with the apex closest to the ground (see **Figure 4**). They do not have moving parts.
Instead, influent is added to the top of the cyclone at an angle, which creates a strong swirling motion as a result of the tangential entry. This separates the heavy solids by forcing them outward where they move to the base of the cyclone and out

an exit via gravity. The liquid and fine suspended particles swirl to the top of the device as an inner spiral, where they exit via a pipe. Cyclones are cheap and versatile (Kruger *et al.* 1995). However, they require booster pumps able to apply the influent at a pressure of at least 30 psi (Mukhtar *et al.* 1999).

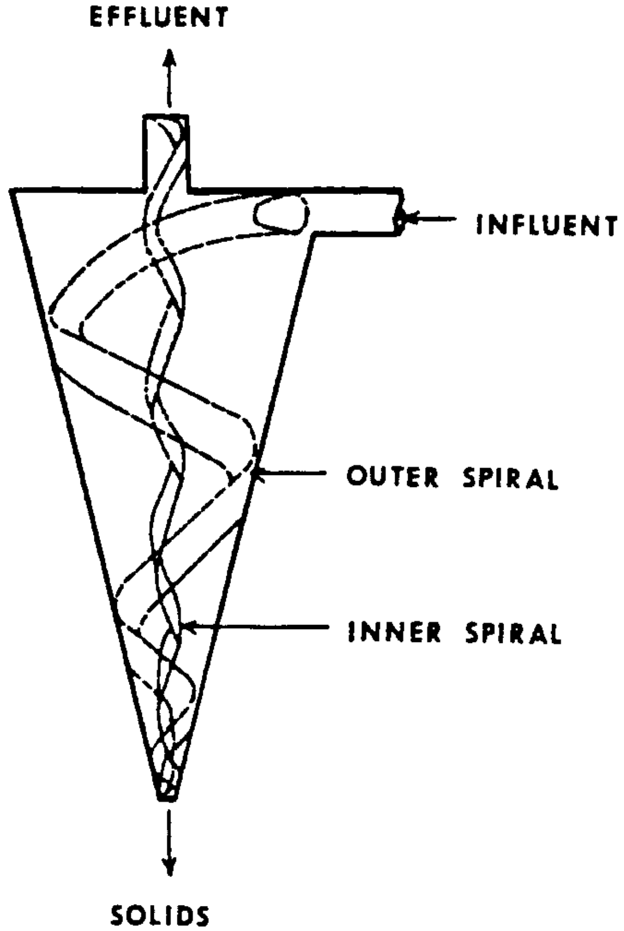


FIGURE 4– LIQUID CYCLONE

Cyclones are well suited to removing fine particles after preliminary solids removal.

FAN Engineering have produced a sedimentation centrifuge separator (SCS) for removing particles sized from 10-100 um. Influent is tangentially fed into the SCS. A rotor accelerates the suspension. Centrifugal forces separate particles with a density exceeding 1 g/cm^3 from liquid and lighter particles. The separated liquid moves out the top of the device, while the solids are voided through the base. The centrifuge comes in different sizes capable of treating 10 m^3/hr, 30 m^3/hr and 100-120 m^3/hr. It is claimed that this device can achieve up to 90% (presumably of TS) from a solution containing 4% TS, although the specification lists up to 80% reduction. No details on the dryness of the solids removed are provided.

It is claimed that cyclones have excellent solids removal capacity (up to 80-90%). No independent research data or details of the dryness of the solids removed were found. Cyclones may have a role for removing solids that cannot be removed by

other primary separation devices or DAF systems. They are compact, inexpensive and versatile.

5.2.4 Centrifuges

Centrifuges use both a screen, and the density difference between solids and liquid, to remove solids. They comprise a cylindrical screen that spins to create centrifugal forces. This causes solids to collect on the screen, and liquids to pass through the screen. An auger insider the cylinder spins faster than the cylinder to remove the solids via an opening at one end of the cylinder (see Figure 5). The major disadvantage of centrifuges is their high capital and operating cost (Kruger *et al.* 1995).

Centrifuges produce dry solids that are readily handled and have minimal odour (Kruger *et al.* 1995). One manufacturer claims an average solids TS content of 28-30%, with a range of 25-35% (Fulhage & Pfost, 1993). Kruger *et al.* (1995) claims an average TS content of 35%.

Hahne *et al.* (1996) cited by Westerman and Bicudo (1998) examined the performance of a decanter centrifuge for separating solids from piggery effluent. They used influent containing 7% TS and an inflow rate of 1.2-2.7 m^3/h. They found that the centrifuge removed 54-60% of TS, 20-30% of N and 70-78% of P_2O_5. The TS concentration of the solids removed was 20-30%.

Piccinini and Cortellini (1987) (cited by Casey *et al.* 1995) investigated both horizontal and vertical centrifuges. The horizontal centrifuge was tested with an influent flow rate ranging from 0.03-0.072 m^3/s. For the horizontal centrifuge, the optimal TS removal rate was 60.5%, with a mean removal rate of 44.6%. The addition of cationic polyelectrolyte increased the optimal TS removal rate to 81.6%, with a mean of 59.3%. Irrespective of whether polyelectrolyte was added, the solids removed had a TS content of about 22.4%. The vertical centrifuge removed a much smaller volume of solids (average 6.1%) and the solids removed were moister, having a TS concentration of 17% on average. It was also demonstrated that the separating efficiency of centrifuges increases with TS concentration in the influent. Although the electrolyte improved removal rates, the authors expected that this would not be cost-effective.

The performance of a single centrifuge in Western Australia was examined by Payne (1990) (cited by Casey *et al.* 1995). The device removed 37% of TS from the influent. The solids produced had a TS concentration of 35.4%, and were sufficiently dry for easy handling.

The solids removal efficiency of centrifuges increases with TS concentration in the influent.

Horizontal centrifuges seem to work significantly more effectively than vertical centrifuges. Average TS removal rates of about 35-45% can be expected, although removal rates of up to 60% TS are achievable. The TS content of the solids removed is typically 20-35%.

With the addition of coagulant average TS removal rates of about 60% can be achieved, although removal rates exceeding 80% are possible. However, the cost of

adding the coagulant may not justify the improved performance. Centrifuges have high capital and operating costs.

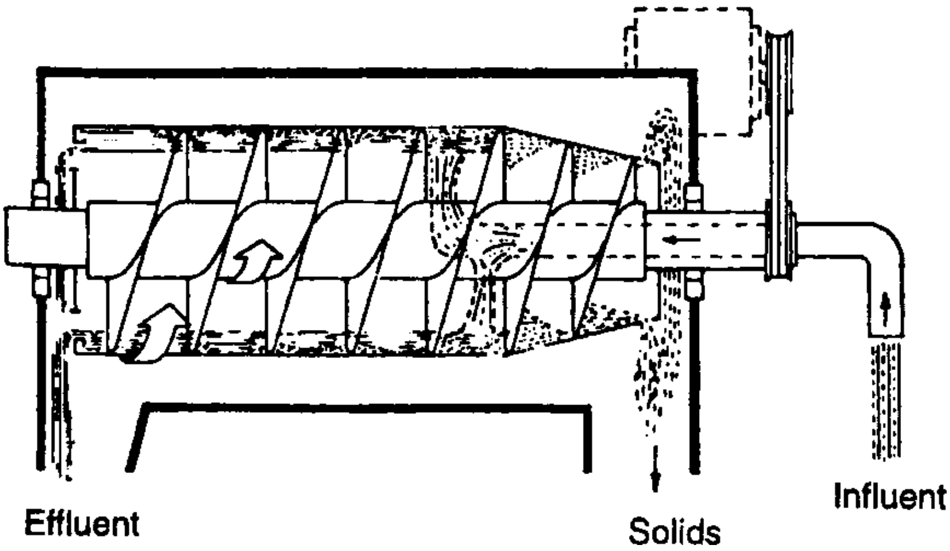


FIGURE 5 – SOLID BOWL CENTRIFUGE

5.2.5 Tangential Flow Separator

A tangential flow separator (TFS) consists of a lime slurry tank, a pre-flocculation tank, a TFS tank with conical base, a thickening tank with a conical base and associated pumps and flow meters (see Figure 6). Lime from the lime slurry tank is added to the screened influent. The slurry then passes into the pre-flocculation tank. Other additives may be injected prior to the slurry being introduced to the thickening tank. The TFS tank acts like a cyclone since the slurry is added tangentially to the wall of the tank and solids gradually settle to the bottom while treated liquid is discharged from the top for lagoon treatment. The settled solids are directed to a thickening tank with a similar design to the TFS tank. This concentrates the solids up to 5% TS. Further dewatering of the solids is subsequently needed (Westerman & Bicudo 1998).

Westerman and Bicudo (1998) tested the effectiveness of a TFS used with chemical additives. They firstly tested screened piggery flushing water then with lagoon effluent. The pumping rate was 3.4 m^3/hr to 4.5 m^3/hr. Lime and $FeCl_3$ were added to the influent at varying rates.

The flushing water had a TFS content of 1.11%, which was reduced to 0.96% after screening. The system removed 34% of TS and 90% of phosphorus. However, a high pH, assisted by the addition of lime, is needed to facilitate very high rates of removal (up to 99%). Two tests using less than 250 mg/L $FeCl_3$ produced phosphorus removals of 65-80%. On average, the system removed 22% of total Kjeldahl nitrogen and 8% of ammonia-nitrogen. It is expected that higher removal rates for ammonia-nitrogen might have been achieved had sufficient lime been added to maintain pH above 9.5. However, this may be expensive compared with using metal coagulants. It was concluded that the addition of about 200 mg/L lime,

200-300 mg/L $FeCl_3$ and 10-20 mg/L polymer was sufficient to produce effluent with a very low phosphorus and suspended solids (SS) (Westerman and Bicudo 1998).

The TFS system was less efficient at removing solids from lagoon effluent, probably because most of the solids are dissolved in the liquid rather than suspended. This makes it difficult to destabilise the solids without the addition of chemicals. Lower chemical usage also removed less solids. Removal of TS and SS were only 9% and 35% respectively. On average, 80% of total P was removed, although the efficiency declined with reduced concentrations of chemicals in the influent. TN and ammonia N removal rates were similar to those achieved for flushed liquids (15% and 7% respectively) (Westerman and Bicudo 1998).

The separated solids had a TS content of about 40% (Westerman and Bicudo 1998).

An odour evaluation indicated that there was no significant difference in odour intensity, irritation and pleasantness between flushed liquids and separated liquids. However, odour from the TFS thickened sludge was found to be significantly more intense, irritating and unpleasant that odour from the TFS supernatant. Lagoon liquid had a significantly lower odour intensity than the TFS supernatant or thickened sludge. The increased odour as a result of treatment is probably due to the creation of odorous compounds from the addition of chemicals.

Wandalup Farms south of Perth, WA, operate a 2000-sow farrow-to-finish piggery. They have installed a rotary screen and a tangential flow separator to remove solids prior to lagoon treatment. The main aim is to significantly reduce the phosphorus content of the effluent that they irrigate. Hence, lime, $FeSO_4$ and polymer are added to the effluent to enhance phosphorus removal and solids flocculation. The tangential flow separator removes about 20 m^3 of sludge with a TS content of about 20%. This material is combined with the screenings for composting (Wilson 1998).

Miller *et al*. (2000) have prepared an interim report on the QED TFS (similar to the device used at Wandalup Farms). In this system, liquids for treatment are introduced tangentially to a cylindrical vessel with an inverted conical base. The solids pass to the base of the vessel and are discharged as a slurry to a thickening tank. The liquid leaves the centre of the top of the vessel. It is claimed that the system removes at least 60% of BOD; at least 90%, but more typically 98%, of SS; at least 25% of sulphides; and at least 10%, but more typically 50%, of ammonia from piggery effluent. Secondary treatment may comprise a QED biofixation/fine bubble aeration combination with short contact times. This process removes at least a further 50% of BOD, 99% of sulphides and 95% of ammonia. The process takes 6 hours of treatment (Miller *et al.,* 2000).

The sludge from the combined process contains about 6% total solids. Dewatering using a press or centrifuge can increase the solids content to 25-35% (Miller *et al.* 2000).

TFS's are far more sophisticated than the technologies previously discussed. They are often adopted where very high phosphorus removal rates are needed to satisfy a particular environmental constraint. Using an influent concentration of about 1% TS, and with the addition of lime and other chemicals, they are able to remove 34% of TS and at least 90% of phosphorus. The separated solids have a TS content ranging from about 6-40%. For lower TS contents, dewatering using a press or similar would

be desirable. The costs of purchasing and operating a TFS are very high relative to other technologies.

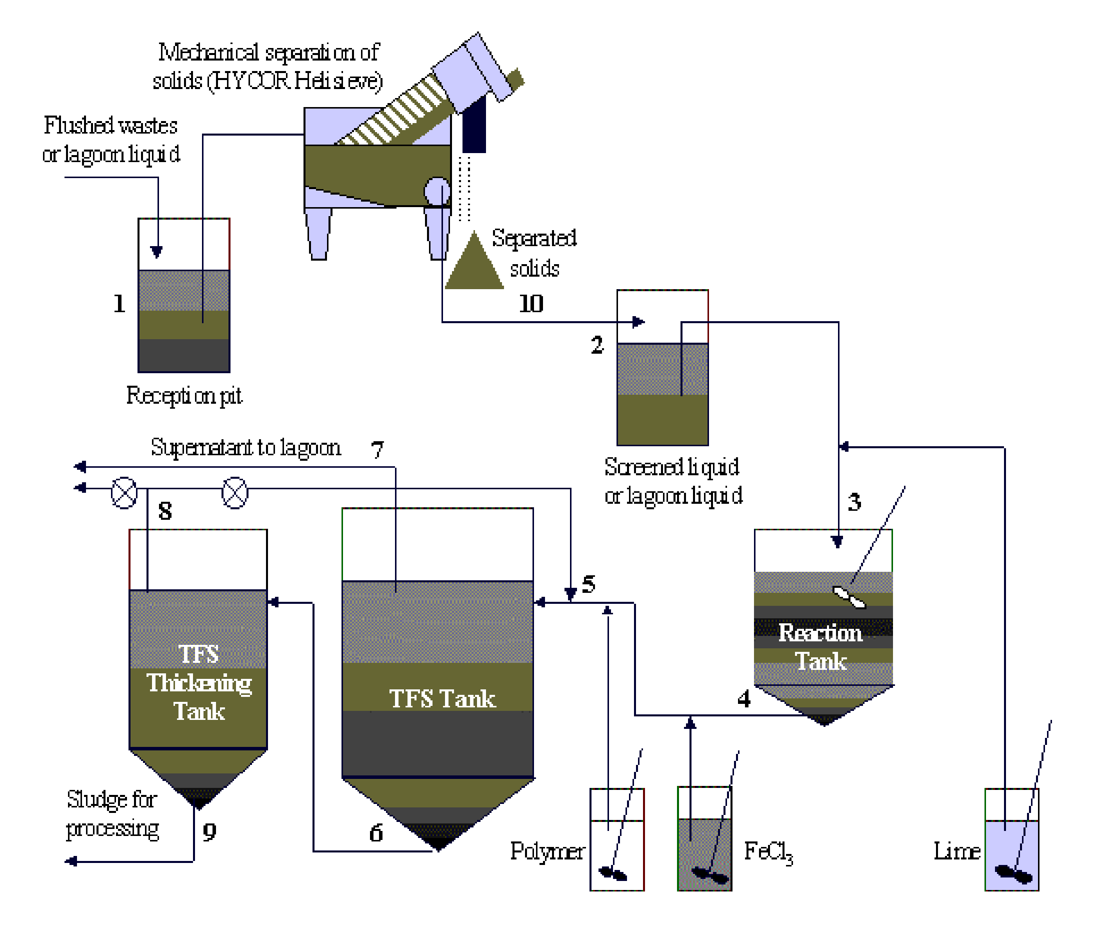


FIGURE 6 – TYPICAL TANGENTIAL FLOW SYSTEM FLOW DIAGRAM

(taken from Westerman & Bicudo, 1998)

5.2.6 Flotation

Flotation is a gravity separation process that removes solids attached to air or gas bubbles. The gases, and attached particles, float to the surface because the gases have a lower density than the liquid. There is a range of methods for introducing the bubbles. The most common is dissolved-air flotation (DAF). In a DAF system, effluent is introduced to a tank. Air is then dissolved in the liquid under pressure. As the pressure drops to atmospheric, the air bubbles form. DAF systems work where the effluent contains a large amount of floating material, although it also removes colloidal and dissolved materials. The fine particles form a scum that is skimmed off. Heavy solids form a sediment that is discharged from the base of the tank via an outlet. Clarified liquid discharges via a weir. Chemical additives may enhance the process (Kruger *et al.* 1995).

Flotation systems require detailed engineering design. They have high capital, operating and maintenance costs (Kruger *et al.* 1995).

Although DAF's are widely used in abattoirs and rendering plants, they have not been widely adopted in piggery effluent treatment. Berrybank (see Section 7.10.1) is the only known example in Australia. However, FAN Engineering manufacture a DAF system that could be used for treating piggery effluent.

5.2.7 Settling

The effectiveness of settling devices depends on the density differences between the solids and the liquid. A basin or tank can be used for settling. Tanks may use continuous flow or batch technology. For basins, settling occurs when the velocity of the liquid is slowed to allow it to spread across the floor of the basin, and the heavier and denser particles are pulled to the bottom by gravity.

According to Kruger *et al*. (1995), about 60% of the VS in piggery effluent will settle by gravity. A detention time of 100 minutes will ensure almost complete settling. However, 50% of solids will settle within 1 minute and 75% within 10 minutes. The remaining VS are colloidal and can only be settled through the addition of coagulants. It is suggested that over 55% of TS, 70% of VS, 20% of N and 40% of P can be settled without the addition of coagulants. Addition of lime may increase the settling rate to 65-70% of TS, 80% of VS, 30-35% of N and 70-90% of P (Kruger *et al.* 1995).

Settling basins should be shallow, typically 0.3-1.0 m deep, long, wide and free draining. The design flow rate should be less than 0.3 m/s, with a hydraulic retention time of at least 20-30 minutes (Mukhtar *et al.* 1999). (Barker 1996) suggests that settling basins should be 0.6-1.0 m deep, with a concrete floor and walls. A front-end loader should remove solids every 1-2 months (Barker 1996). Regular sludge removal is necessary to prevent the development of septic conditions and sludge re-suspension. Removal of sludge may be difficult. For this reason, concreted or trafficable basins are recommended (Kruger *et al.* 1995).

Barker (1996) also suggests building an earthen settling basin able to store 6-12 months solids. He suggests a basin top width of 30 m or less, a length to width ratio close to 3:1 and a liquid depth of 2.5-3 m. He suggests mixing the basin contents thoroughly prior to land spreading using a liquid manure spreader or slurry irrigator (Barker 1996). However, this device is very likely to behave like an overloaded anaerobic pond and is not recommended unless covered due to odour problems.

An alternative idea is the SEP's (sediment and enhanced evaporation pans) developed by the Walker family at Young. The system was developed because of difficulties with irrigating effluent – elevated soil nutrient levels, difficulties in irrigating effluent during wet winters and steep land. The system comprises three or four evaporation pans about 500 m long, with a base width of 6-10 m and a top water level width of 20 m. The lagoons are built on the contour. Being shallow, they are relatively cheap to build. A contour drain above the SEP diverts stormwater runoff away from the SEP (Walker, 1998)

The three SEP's are used independently, hence when one SEP is filling, another is drying. Effluent is added to the "current" SEP and the liquid slowly moves to the other end. The cleanest water is drawn from the end furtherest from the influent delivery point. This is pumped to storage dams. Surplus effluent is irrigated. As the sludge in the SEP dries, a crust forms inhibiting further drying. Drying is enhanced

by breaking the crust. When the sludge becomes sufficiently dry, the sludge is removed using a blade, front-end loader and truck (Walker 1998).

According to Ian Kruger of NSW Agriculture, the SEP's work very well and do not smell.

Sedimentation tanks avoid the solids removal and potential odour issues associated with basins. However, they may be relatively expensive. Barker (1996) suggests a large rectangular, metal or concrete settling tank. He recommends a liquid depth of 2.5 m and a 3:1 length to width ratio with tank volume being determined by the volume of influent for treatment. Detention time should be 10-30 minutes.

Tanks may be operated in batch or continuous mode. When operated in batch mode, the effluent is poured into a tank and allowed to settle. The supernatant is discharged from the tank when settling is complete or it slowly drains out of the tank. A bottom scraper may transfer solids to a storage hopper. If operated in continuous mode, complex flow monitoring and chemical dosing equipment is required. These systems have higher capital, operating and maintenance costs compared with batch tank systems. The operating costs depend on the degree of automation and the chemical usage (Kruger *et al.* 1995).

Oleszkiwicz (1979) (cited by Casey *et al.* 1995) suggested that aerating effluent for 30 minutes prior to settling improves the solids settling rate by 4%. He indicates that 75% of total suspended solids are removed after 30 minutes of settling, with only a marginal improvement over longer time periods. The BOD removal rate was 35% and the COD removal rate was 55%.

Settling has the potential to remove more solids than most alternatives, but requires more management. There is potential for significant odours if settling basins are not regularly cleaned. For that reason, concreted trafficable sedimentation basins, or batch-operated sedimentation tanks, are recommended. About 75% of the VS in effluent may be settled within 10 minutes. This can be increased to 80% of VS with the addition of lime. Addition of lime and other chemicals can also achieve high levels of nutrient removal.

SEP's also show good potential, however these need to be proven in a range of Australian conditions.

5.2.8 Biomass Filter

Iowa State University is investigating the use of a biomass filter to separate solids from liquids. The concept is to use crop residues as a filter for effluent prior to lagoon treatment. Some very preliminary research was conducted by drilling holes in the base of a bucket, filling the base with soybean stubble and pouring piggery manure slurry through the bucket. The TS concentration of the slurry was 1.86%. Two trials showed a TS removal rate of 54.3% and 60.2%. There was little or no detention time, so solids removal was attributed to filtering rather than settling. Further laboratory research was to follow. It was hoped that these would show how long each batch of residue can be used. Different influent solids concentrations will also be used. It is expected that spent filter medium would be useful for composting (Richard *et al.* 1999).

This technique is too new to be recommended.

5.2.9 Coagulation and Flocculation

Coagulation and flocculation are relatively new techniques for the treatment of effluent from intensive piggeries, although they are widely used with municipal sewage. The chemicals are used to aggregate suspended solids to form settleable particles (coagulation) and to convert these into large, readily settleable particles (flocculation). These techniques are used in conjunction with other technologies, most notably TFS.

Coagulation gathers solids suspended in a liquid into a mass to form particles that can then settle. Flocculation converts these particles into larger masses that settle more rapidly. Organic polymers such as polyacrylamide (PAM); metal salts e.g. ferric chloride ($FeCl_3$) or alum ($Al_2(SO_4)_3$); and lime ($Ca(OH)_2$) are widely used for this purpose (Mukhtar *et al.* 1999).

Laboratory studies show that ferric chloride and alum are effective coagulants (Mukhtar *et al.* 1999). $FeCl_3$ more effectively removes solids and nutrients from piggery effluent than the other metal salts. Polymers may also be useful, although thy are relatively more expensive than the metal coagulants (Westerman & Bicudo 1998). However, they help in flocculation that improves the solids removal efficiency of screening-type processes (Mukhtar *et al.* 1999).

Laboratory studies also show that higher rates of lime (1500 –2000 mg/L), with or without $FeCl_3$, resulted in the development of large, dense flocs that settle well. Use of $FeCl_3$ at 200 mg/L produced small, reasonably dense flocs with good settling characteristics (Westerman and Bicudo 1998)

Miner *et al.* (1983) (cited by Westerman & Bicudo 1998), investigated the use of alum and Zetag 92, a synthetic cationic polyelectrolyte, for removing solids from piggery effluent using a sedimentation tank. The alum concentration used was typically 300-500 mg/L. The polymer concentration ranged from 0 mg/L to 38 mg/L. They tested these agents with lagoon effluent and lagoon contents. Both alum and polymer improved sedimentation rates, playing an increasingly important role as the flow rate increased above 1.6 m^3/h. The polymer proved more effective than alum at higher sedimentation tank loading rates. For the lagoon effluent, reductions in BOD and COD of 40% and 60%, respectively were achieved. For the lagoon contents, reductions in BOD and COD of 70% and 80%, respectively were achieved.

Hanna *et al.* (1985) (cited by Westerman & Bicudo 1998) examined the effect of $FeCl_3$, chitosan and a cationic polymer on pig and beef cattle effluents. The performance of these compounds was measured against a control that was simply stirred and allowed to settle. They recorded VS removal rates of 26%, 56%, 31% and 21% for $FeCl_3$, chitosan, the cationic polymer and the control, respectively. This suggests that the chitosan had a marked effect on settling, while the cationic polymer and $FeCl_3$ had a less significant effect.

5.2.10 Summary of Solids Separation Options

TS removal rates for the various screens vary widely. However, run-down screens and vibrating screens remove more solids than rotating screens. TS removal rates for run-down screens range from about 10% to 35%. Vibrating screens generally remove about 20-27% TS. Rotating screens are reported as removing about 4-14% TS. Rotating screens remove more solids if lower rotational speeds are included in the speeds used. Vibrating and rotating screens produce significantly drier solids than run-down screens. This has important implications for handling and management. Vibrating screens produce solids with a TS content of about 12-21%. For rotating screens, TS concentrations in solids range from about 12-17%. For run-down screens, solids typically contain 6-10% TS. At these TS concentrations, the screenings from run-down screens are still slurries, and very difficult to handle. Blinding is a significant problem with screens, particularly fine screens. The only prevention is regular cleaning, although some more sophisticated screens are fitted with continuous cleaning devices. Stationary run-down screens are considerably cheaper to purchase and operate than the more sophisticated screens or alternative separation devices. However, because vibrating screens have good solids separation properties and produce drier solids, these may be preferred.

The removal efficiency of press screw separators depends on the size of the screen fitted, the TS content of the influent and the influent delivery rate. Using a 0.5 mm screen, press screws can remove over 85% of TS and about 90% of VS. Lower solids removal is expected with a coarser screen, although this depends on the influent delivery rate. It appears that press screws are significantly less efficient if the effluent stream has an inconsistent or low TS content. Under ideal operating conditions, average TS removal rates of 55-80% could be expected. No data for a press screw used with coagulants was available. The dry matter content of the solids removed by presses is typically 20-30%. This means the solids are readily manageable. A belt press used with coagulants is able to remove 71-78% TS from dairy cow effluent. The solids removed have a TS content of 20-22.8%. This suggests similar performance between screw and belt presses.

Horizontal centrifuges seem to work significantly more effectively than vertical centrifuges. Average TS removal rates of about 35-45% can be expected, although removal rates of up to 60% TS are achievable. The TS content of the solids removed is typically 20-35%. The solids removal efficiency of centrifuges increases with TS concentration in the influent. With the addition of coagulant average TS removal rates of about 60% can be achieved, although removal rates exceeding 80% are possible. However, the cost of adding the coagulant may not justify the improved performance. Centrifuges have high capital and operating costs.

It is claimed that cyclones have excellent solids removal capacity (up to 80-90%). No independent research data or details of the dryness of the solids removed were found. Cyclones may have a role for removing solids that cannot be removed by other primary separation devices or DAF systems. They are compact, inexpensive and versatile.

A TFS is a sophisticated device that uses lime and polymer dosing to remove solids. It has high capital, operating and maintenance costs. TFS's are often adopted where very high phosphorus removal rates are needed. They are able to remove 34% of TS and at least 90% of phosphorus. The separated solids have a TS content ranging from about 6-40%. For lower TS contents, dewatering using a press or similar would be desirable.

DAF systems are able to remove the potential for use in piggeries. However, they have high capital, operating and maintenance costs (Kruger *et al.* 1995).

Settling has the potential to remove more solids than most alternatives, but requires more management. There is potential for significant odours if settling basins are not regularly cleaned. For that reason, concreted trafficable sedimentation basins, or batch-operated sedimentation tanks, are recommended. About 75% of the VS in effluent may be settled within 10 minutes. This can be increased to 80% of VS with the addition of lime. Addition of lime and other chemicals can also achieve high levels of nutrient removal. SEP's also show good potential, however these need to be proven in a range of Australian conditions.

Iowa State University is investigating the use of a biomass filter to separate solids from liquids. While this technique may have potential, it is too new to be recommended at present.

5.2.11 Cost of Solids Separation

Agribiz Engineering (1999) provides data on the capital and operating costs of various solid separation devices used in Australia. These are given in Table 1.

TABLE 1 – COSTS OF SOLID SEPARATION DEVICES

(adapted from Agribiz Engineering, 1999)

	Size of Piggery	
	2000	**20000**
Capital Costs		
Screen	$ 8,500	$ 30,000
FAN Screw Press		$ 70,000
Centrifuge		$ 200,000
Concrete Works	$10,000	$ 40,000
Pumps & pipework	$ 10,500	$ 21,000
Front End Loader	$ 50,000	$ 82,000
Total Capital Cost	$ 79,000	$ 173,000 - $ 343,000
Annual Operating Costs		
Labour	$ 5475	$ 32,000
Repairs & Maintenance	$ 1050	$ 5000-$12000
Energy	$ 493	$ 3500 - $25000
Total Operating Cost	$ 6768	$ 40,000 – 70,000
Total Annual Cost (including capital)		
Screen	$ 11,300	$ 56,000
Screw Press		$ 60,000
Centrifuge		$ 110,000

5.3 Anaerobic Lagoons

McGahan *et al*. (1996) surveyed piggeries in Queensland. They found that over 90% of piggeries had an anaerobic lagoon (see Photograph 5). They found that the overall average anaerobic lagoon volume was 4.2 m^3/pig. However, it was found that 68% of piggeries did not provide 4 m^3/pig. In fact 44% of lagoons provided less than

2 m^3/pig. Kruger *et al.* (1995) estimated that about 59% of piggeries used anaerobic lagoons, 27% used direct land application, 9% used deep litter or extensive systems and 6% used various other methods. Clearly, anaerobic lagoons are the major method for treating piggery effluent in Australia.

Anaerobic lagoons provide a convenient and simple method for stabilising organic matter into less reactive compounds and gases. Anaerobic digestion is a two-stage process. In the first stage, the organic matter in effluent is broken down to form volatile fatty acids (VFA's). In the second stage, these VFA's are converted to inoffensive methane and carbon-dioxide. However, methane-forming bacteria are highly sensitive to pH. If the pH of the effluent in the lagoon becomes too acidic, the second stage will be impaired and the odorous VFA's will be released. The lagoon often becomes too acidic as a result of over-production of VFA's. This is generally caused by overloading with organic matter, either continuously (i.e. the pond is under-sized or needs desludging) or as surges. Hence, design of anaerobic lagoons should use an organic matter loading rate method.

Anaerobic lagoons are typically 4-6 m deep but can be deeper. As a rule of thumb, 6-8 m^3 of pond volume should be provided per standard pig unit (SPU), although lesser volumes e.g. 4-6 m^3 or less are possible with efficient solids removal. A more accurate method for sizing anaerobic ponds is to use an organic loading rate method to size the treatment capacity plus an allowance for sludge storage. The most common organic loading rate method for piggeries is a sizing based on volatile solids (VS) and K factors. For the Murray Bridge area, Kruger *et al.* (1995) suggest a K factor of 0.73, which translates to a VS loading rate of about 73 gVS/m^3/d. A further 25-40% of pond volume should be added for sludge storage. Anaerobic ponds are generally designed with a length to width ratio of 2-3:1. Influent should be added at a point as far away as possible from the effluent outflow/draw-out point. These design criteria maximise the length of time that effluent takes to travel from one side of the pond to the other, hence maximising treatment time.

PHOTOGRAPH 5 – TYPICAL PIGGERY WITH ANAEROBIC LAGOONS

Anaerobic lagoons are an economical method for treating effluent. They are able to treat high strength effluent and have some tolerance of variations in the quality and composition of effluent for treatment. However, malfunctioning anaerobic ponds can produce offensive odours. In addition, removal of sludge from these ponds can release offensive odours.

5.4 Stratified Lagoons

Stratified lagoons are really anaerobic ponds with shallow mechanical aerators installed to aerate the surface of the lagoon to control odour (see Section 6.6.4). The function of these ponds is temperature-dependent, but they work well in semi-tropical to tropical climates. One kilowatt of power should be provided for every 150 m^2 of lagoon surface area (Kruger *et al.* 1995). Aeration involves significant capital cost and ongoing operating expenses.

5.5 Facultative Lagoons

Facultative lagoons combine the features of both anaerobic and aerobic lagoons. The surface acts aerobically, the sub-surface anaerobically to provide further treatment. Facultative lagoons are typically 1.5-2.5 m deep. In Australia, they are typically designed to have the same surface area as the accompanying anaerobic pond, for simplicity of design (Kruger *et al.* 1995).

Iowa State University (ND) suggests that the required surface area of non-aerated facultative lagoons renders them impractical for treating livestock influents. They suggest designing facultative ponds for mechanical aeration at the rate of 22 m^2/kW of aeration power. A hydraulic retention time of 20-30 days is also suggested. However, if ponds are designed this way, they are effectively a stratified lagoon.

5.6 Aerobic Lagoons

The water in aerobic lagoons has a high oxygen content relative to other types of lagoons, and is able to support aerobic microorganisms. Algae in aerobic lagoons gives the lagoon a colour varying from green in winter to pink in summer (Kruger *et al.* 1995).

Naturally aerated lagoons are 1-1.5 m deep to allow for light penetration and oxygen transfer. Loading rates of up to 50 kg BOD_5/ha-day are recommended, although rates of up to 400 kg BOD_5/ha-day are possible for lagoons less than 0.5 m deep. Ideally the solids concentration should be 0.1-0.2%, although concentrations of up to 0.5% are acceptable. However, non-aerated aerobic lagoons are impractical for large volume, high strength livestock influents (Iowa State University, ND).

Mechanical aerators allow lagoons with relatively small surface areas to achieve the odour control benefits of aerobic digestion. Aeration is a proven technique for reducing odour from effluent. Research has demonstrated that aerated lagoons emitted 82% less odour than a similar non-aerated lagoon with only half the volumetric loading rate (Heber, 1998).

The cost for energy to run aerators is high because it is expensive to transfer oxygen to liquid (North Carolina State University, 1998). Typically the aeration design should

supply 1-2 times the BOD input. However, lower levels will provide some odour control (Iowa State University, ND). For example, some BOD reduction can be achieved by supplying oxygen to about a third of the BOD loading. However, if there is insufficient oxygen, anaerobic conditions and foul odours may occur. Sludge formation is also much higher under aerobic conditions than anaerobic conditions (North Carolina State University 1998).

5.7 Evaporation Basins

The use of evaporation basins is often limited by their large size and design standards (e.g. more rigorous overflow frequency) in comparison with systems that use treatment and irrigation of effluent. However, evaporation basins are effective in dry regions where evaporation rates greatly exceed precipitation. (Mukhtar *et al.* 1999). They are suited to the Murray Bridge area and can be used in conjunction with an anaerobic pond.

5.8 Constructed Wetlands

Constructed wetlands or reed-beds (see Photograph 6) have been widely used to remove nutrients from secondary-treated municipal sewage, which is far more dilute than piggery effluent. Constructed wetlands are only a polishing device and are not suitable for treatment of high strength wastes. If a wetland were used at a piggery, it would follow after the anaerobic and secondary ponds. We are not aware of any constructed wetlands for treating piggery effluent in Australia.

Because high ammonia concentrations may kill aquatic vegetation, dilution of treated piggery effluent in a 1:1 ratio with clean water may be necessary. Wetlands typically reduce nitrogen concentrations by over 85%, phosphorus by about 70%, total suspended solids by 80% and BOD by 85%, although treatment efficiency declines in winter. Although wetlands can reduce nutrient concentrations, information on nutrient budgets are needed (Kruger *et al.* 1995).

Constructed wetlands must be no-discharge systems. Effluent should be irrigated from the wetland. A wetland can reduce the land area required for irrigation by 75% (Kruger *et al.* 1995).

No data on odour levels from constructed wetlands for treating piggery effluent is available but the odour emissions should be low.

Because of the high evaporation to rainfall at Murray Bridge, the effective function of a constructed wetland for treating piggery effluent is doubtful.

PHOTOGRAPH 6 – CONSTRUCTED WETLAND

5.9 Under-Slat Scrapers

Under-slat scraper systems have the potential to eliminate anaerobic lagoons altogether. These systems eliminate the use of flushing water, instead relying on scrapers to remove manure from the under-pen channels. Usually, the scraper device comprises a blade that is pulled along the surface of the flush channel, pushing the manure slurry in front of it.

It is possible to fit under-slat scrapers or open-channel scrapers to most existing buildings. Open channel scrapers are less expensive to install and more easily maintained. However they are not recommended because pigs can be caught between the scraper and pen partitions. There is also the potential for transfer of disease and drugs from one pen to another (Dickey *et al.,* 1996). Dry scraper systems are favourable as they offer reduced water usage and more cost-effective manure management (White, 1998). These disadvantages are minimised through the use of an under-channel scraper. The down-side is that it can be difficult to repair and maintain the system because of the need to access parts under slats. This problem can be minimised by making some slats removable to allow for easier access. Ammonia build up in buildings may also be a problem (Dickey *et al.,* 1996).

Robert Fielke has installed a dry scraping system to his piggery sheds at Loxton in South Australia. A continuous steel rope pulls a scraper up and down the channels previously installed for flushing. The scraper is powered by an electric motor that is controlled by micro-switches. In plan-view, the scraper is V-shaped with a third arm between the arms of the V. This middle arm is attached to the steel rope that pulls the scraper along. When the scraper is pulled towards the storage pit, the manure is stored between the two arms of the scraper as it is pulled along the channel. However, once the scraper has emptied it's load, it must be returned to the top of the channel. On this empty run, the outer two arms of the scraper collapse inwards. The operating costs of the system are minimal. It is therefore feasible to drag the pit several times a day to minimise ammonia build-up (White 1998).

White (1998) claims that the dry system used by Robert Fielke is consistent with a healthy shed environment. He also indicates that the system is very robust and effective. He states that there is very little chance of the steel rope breaking as the scraper blades are shallow and bear little weight and the rope has a very high breaking strain. However, the manure is still dumped in an open manure pit. The

solids content of the effluent removed is about 15%, which reduces the likelihood of seepage to groundwater.

According to Chris Harris, (pers. comm. 31 March 2000; 5 April 2000), Robert Fielke's system works well. A limitation is that the life of the galvanised cables is only about five months. Also, the system is currently operated at 6 AM and 6 PM. It is suggested that ammonia levels in the shed could be reduced by scraping the channels when the shed sides, or the roof ridge ventilator, is open. The effluent has a semi-liquid consistency. The moisture content of the effluent could be reduced by using bowl drinkers, or perhaps by using a press screw to remove moisture. The effluent is currently scraped into a series of lagoons, which have crusted over. This is a potential odour source. More work needs to be put into the management of the scraped manure.

According to White (1998), the cost of converting underfloor pits to a dry scraper system is less than $1000 per pit for materials and equipment, assuming that no extra earthmoving or concreting is required. Depending on the site, it may be necessary to use a manure pump to load the solids into a storage. This adds to the capital and maintenance costs of the system. However, a benefit is the high retention of nutrients. Use or sale of these solids may allow these capital and operating costs to be offset (Dickey *et al.* 1996).

The solids removed using a dry scraper can be handled using a chopper-agitator pump and a non-vacuum tanker. If the material is to be spread directly, manure injection will reduce odour potential and nitrogen losses. There is a high potential for odour generation during land application (Dickey *et al.* 1996).

Composting of the solids immediately after collection is recommended. The solids should be depositing onto a concrete pad and allowed to drain (to a lagoon) prior to composting. Alternatively, a solids separation device should be used to remove some of the liquid, making the material more suitable for composting.

5.10 Deep-Litter Systems

Low-cost, deep-litter shelters were first developed in Canada over 15 years ago. The shelters consist of steel-frame structures covered with plastic, timber side-barriers and earth floors. A layer of deep litter is placed over the earth floor to act as bedding for the pigs and to absorb manure. Deep-litter systems are usually used for growing and finishing pigs, typically aged from 10 weeks to 23 weeks. They are an all-in, all-out system. At the end of a growing period, the pigs and litter are removed. Clean litter is placed in the shelter prior to the introduction of new pigs. Photograph 7 shows weaners newly introduced to a deep-litter shed that uses sawdust as the bedding. Photograph 8 shows the same shed with the pigs at the grower stage.

In the USA, this type of pig housing is called a hoop structure. Iowa State University has been studying this system for a number of years. Information is available at www.ae.iastate.edu/hoop_structures/hoop_basics.htm. In the USA, corn stalks are used as deep litter. In Canada, these systems are known as ecobarns.

This pig production system has increased in popularity in Australia in the last five years, mainly due to the low capital cost (about $80/pig place or $100/pig place, including concrete floor). However, there are also environmental advantages with

dry manure handling. It is claimed that these structures have little odour compared with conventional pig housing.

In Australia, the *ClearSpan Shelter* and the *EcoShelter* have been developed commercially. In New South Wales, corrugated iron sheds comprising a skillion roof, one fully open side and three partially open sides have also been successfully used (ecosheds). The Menangle and Boen Boe piggeries near Sydney have also recently converted some conventional sow accommodation to a bedding-based system. This has been achieved by covering or replacing the slatted flooring with a solid floor and removing crates so groups of sows run in pens together. Feeding is *ad lib.* The adoption of this accommodation for sows is too new for any conclusions to be drawn about it's success. However, managers of both piggeries have observed that the *ad lib* feeding results in sows becoming too fat which shortens the length of time that they can be kept for breeding (Hugh Payne, Agriculture WA, pers. comm. 5 April 2000).

Payne (1997) has undertaken a comprehensive research project into low-cost housing in Western Australia. This study included animal performance, management and environmental performance. In Australia, the litter used is usually barley or wheat straw but can include rice hulls or sawdust (see Photograph 7). Floors may be earth, compacted gravel or concrete. Concrete is a more expensive flooring. However, it is recommended in situations where there are light soils and/or shallow groundwater, since nutrient leaching may be an issue. Hugh Payne (pers.comm. 5 April 2000) also suggests that less bedding is used in concrete-floored eco-shelters, the spent bedding is more easily removed and the bedding is not contaminated with gravel and clay.

From personal communications with Hugh Payne (pers. comm. 5 April 2000), ecoshelters and ecosheds work well with grower-finisher pigs if all-weather access is possible and if the structures are located on built-up pads or bunded areas that preclude entry by stormwater runoff.

A significant limitation of bedded systems is their reliance on bedding for their operation. In South Australia, the major bedding source is probably cereal straw. This will be a very scarce and expensive commodity in a drought, raising the cost of production. Straw, or substitutes, could be pre-bought and stored on-site. However, this has costs also, since the bedding must be protected from fire and rain. In these systems, equipment is also needed to manage the placement and removal of bedding, and the spreading of spent bedding on land.

More stringent management is required for bedded systems than for conventional sheds. Uneven finishing of pigs can be a problem. Some manager's overcome this by drafting pigs and undertaking final finishing in conventional accommodation. However, for large piggeries, pigs could be drafted and finished in groups in ecoshelters or ecosheds.

Concerns about impacts of bedded systems to animal health have been raised. While research in Western Australia demonstrates that air quality in terms of dust, endotoxins and fungi is worse in ecoshelters compared with conventional sheds; no adverse impacts to animal health or performance have been observed to date (Hugh Payne, pers. comm. 5 April 2000). This may be because the removal and replacement of bedding after each batch of pigs ensures that the accommodation is clean. Thorough cleaning of pens in conventional piggeries does not necessarily occur.

PHOTOGRAPH 7 – NEWLY INTRODUCED WEANERS IN DEEP-LITTER SYSTEM

PHOTOGRAPH 8 – GROWERS IN DEEP-LITTER SYSTEM

5.11 Composting

Separated solids typically have a high moisture content. They generally require drying prior to removal off-farm, or reuse on farm. Composting allows the solids to be dried and stabilised prior to use.

Composting is an excellent method of treating solid by-products prior to land spreading or sale. The product of the composting process is a stable soil conditioner. The product improves the physical, organic and chemical properties of the soil (Kruger *et al.* 1995). If correctly undertaken, composting is an aerobic process, so odours associated with anaerobic decomposition are minimised (Potts *et al.* 1999).

Composting uses micro-organisms to break-down organic matter to form a humus-like substance. The process occurs in the presence of the right micro-organisms, and if there is sufficient carbon, oxygen, water and nutrients to stimulate microbial growth (Potts *et al.* 1999). According to Kruger *et al.* (1995), the mixed raw products for composting should have a carbon to nitrogen ratio of 25-30:1, a moisture content of 50-60%, a pH of 6.5-8.5 and a density of 640 kg/m^3 or less. However, Potts *et al.* (1999) cite a broader carbon to nitrogen ratio of 15:1-30:1 and a moisture content of 40-50% wet basis.

Solids removed from the effluent stream are generally too moist to be composted on their own. Hence, bulking agents must be added to the solids to reduce the moisture content of the material (co-composting) and to also achieve a suitable carbon to nitrogen ratio. Addition of a bulking agent also incorporates the oxygen needed for microbial activity. The initial mixing of ingredients adds oxygen, although this is quickly exhausted. Turning the piles weekly adds oxygen (Potts *et al.* 1999).

Spent ecoshelter straw has a relatively low water content and bulk density, making it ideal for composting. The low moisture content makes the material easy to transport. The low bulk density indicates that the material contains a lot of air.

There are various methods of composting, although on-farm composting is usually restricted to the aerated static pile and windrow methods due to the higher cost, complexity and labour requirements of the alternative methods (Kruger *et al.* 1995).

The easiest and least expensive system is the aerated static pile method. Separated solids are mixed with a bulking agent. The pile is located over perforated aeration piping. A single aeration pipe is usually adequate for aerating a pile 3-5 m wide, 2-2.5 m high and 25-30 m long. Air is pumped through the pile using a blower. An air flow of 2.8 m^3/t dry solids/minute is usually adequate. However, the pipe sizes and hole layout and design must be carefully designed. It is best to put a layer of woodchips or similar over the pipe before adding the solids. This promotes free movement of air at the base of the pile, and minimises blocking of the air holes. Continuous aeration is recommended for the first 48 hours followed by aeration for ten minutes every hour. Using this system, the active composting period is about 3-5 weeks, followed by a maturation period of at least a month (Kruger *et al.* 1995).

Windrow composting is a more expensive than static pile composting due to the equipment required. However, for farms that already own a front-end loader, it may be a less expensive option. Windrow composting involves placing raw material in long narrow rows that are turned regularly to incorporate air. Typically windrows are 3-6 m wide and 2-3 m high (Kruger *et al.* 1995). Aeration also occurs by natural

convection. Hot air from the centre of the pile rises through the pile creating a partial-vacuum that pulls cooler air into the pile (White 1998).

According to Kruger *et al.* (1995), the active composting process takes about three to nine weeks. However, the shorter composting times require turning the windrow at least daily for the first week and once every three to five days thereafter. Pittaway (NDa) suggests six to eight weeks for composting and a further four weeks for curing. She also suggests that the compost may need to be watered in the first six weeks of the process to allow the centre of the pile to reach field capacity. This is necessary to allow the pile to heat up. This is unlikely to be necessary for wet solids removed from the effluent stream, but may be needed for spent ecoshelter bedding. Over-watering will result in both the leaching of nutrients and the generation of malodours as a result of anaerobic decomposition. If excessive heat is generated, the pile may also spontaneously combust, resulting in more odour.

The composting process will kill weed seeds and pathogens, providing all portions of the compost are exposed to the high temperatures within the core of the windrow. However, turning with a front-end loader does not guarantee that this will occur. It is recommended that the windrows be turned at least three times in the first 15 weeks of composting to ensure that this happens (Pittaway and Roberts 2000).

Because composting is an aerobic process, it is a low odour process. It is strongly recommended that solids removed from effluent streams, and pond sludge be immediately composted to prevent them from becoming a secondary odour source.

5.12 Vermiculture

Vermiculture is an alternative to composting. It allows piggery solids to be converted to a fertiliser substitute. The products are worms, castings and liquid vermicast (White 1998).

Vermiculture facilities require adequate water supply, shade and wind protection. Beds 1 m wide, 2 m long and 0.3 m deep are recommended, although vermicast production requires beds 1 m deep. Beds may be built from brick, cement, hardwood, treated pine or clay banks. The beds must be well drained. Organic matter must be supplied to the worms in narrow layers regularly to prevent overheating of the beds. The beds must be kept moist by regular watering (Kruger *et al.* 1995).

A vermiculture facility was installed at Parkville Piggery in response to a need to treat solid by-products. The piggery produces over 100 m^3 of screened solids each week. Spreading of the solids on-farm was not environmentally sustainable. In addition, sludge from the effluent treatment lagoon could not be economically transported off-site. Hence, a vermiculture system was installed to stabilise the volatile solids and convert the inputs to a marketable soil conditioner. The vermiculture system is capable of accepting 20 m^3/d of solids on a seven-days per week basis with supplementary aeration. The screenings and sludge are combined in appropriate proportions and odour inhibitors are added prior to being added to the plant. The plant is covered to weather-proof the plant, reduce odours and prevent the entry of birds. An automated watering system maintains the optimum moisture content. Leachate is captured and recycled through the watering system. The vermicast is removed when stable and dry (White 1998).

White (1998) indicates that the cost of installing a 100 m^3 Vermitech International system was $198,000. The annual operating costs cited were $93,600 (White 1998). No returns from sales of worms, castings and liquid vermicast are provided.

Vermiculture is an excellent method of treating solid by-products. However, the management requirements and the capital, maintenance and operating costs are considerably higher than for composting.

5.13 Carcass Disposal

Typical mortality rates in piggeries are 2.5% for weaners, 1.5% for growers and finishers and 9% for breeding sows.

In 1995, the Department of Primary Industries, in association with the Queensland Pork Producers' Organisation surveyed 37 Queensland piggeries from 19 shires (mainly on the Darling Downs). The piggeries included units sized from 70-149 pigs to over 20,000 pigs. The survey results indicated that the managers of about half the piggeries buried dead pigs either using a covered (32%) or open pit (11%) or a hole in the ground (8%). Most of the remaining piggeries (43%) burnt the carcasses, with one piggery dumping (3%) and one dry rendering (3%) carcasses (McGahan *et al.* 1996). Since that time, the use of composting for carcass disposal has emerged.

The current options for carcass disposal are:

- Composting

Dry composting aims to reduce the volume and mass of carcasses as quickly as possible, without generating odour or leachate. Because composting is an aerobic process, odour generation is low (Pittaway NDb). Composting also destroys pathogens (Kruger *et al.* 1995). The micro-organisms that compost the carcasses proliferate when the carbon to nitrogen ratio of the substrate is 20-35:1. Hence, carbon must be added to the carcasses to promote composting. Straw and sawdust are both suitable carbon sources (McGahan 1998b). Addition of straw or sawdust also absorbs moisture and masks odours. Sawdust is ideal because it has a small particle size, is easily handled and has a high carbon content. About 6 m^3 of sawdust is needed to compost a tonne of carcasses (Kruger *et al.* 1995).

Composting should be undertaken on a compacted earthen or concreted pad. For permanent composting structures, bays built from concrete or treated wood construction are recommended. Roofing is recommended to control compost moisture content. Bays should be at least 3 m wide with a floor area of 18-36 m^2 and a depth of 1.5 m (Glanville ND).

In Australia, bays are typically formed from large hay bales that are placed end-to-end to form a three-sided enclosure (see Photograph 9). A layout two bales deep by three bales wide works well, providing a floor area of about 12-15 m^2. A surface area of about 0.25-0.3 m^2 is needed for each tonne of carcasses. At least two bays are also needed. Carcasses are added to the first bay until it fills and then the second bay is used. This provides time for the carcasses in the first bay to fully compost before it is needed again (Kruger *et al.* 1995, Glanville ND). When using the large bale bays method, sawdust is an ideal co-composting material since it

forms a surface crust that sheds the rain. This allows for composting to occur without a roof. If straw or other more absorbent materials are used, a roof or tarp may be necessary to prevent saturation and discharge of odorous leachate (Glanville ND).

A layer of sawdust or straw should cover the bay. The carcasses should be placed on top of this material. Splitting the gut of large carcasses helps to minimise expansions of the body (Pittaway NDb). The carcass should then be covered with 0.3 m of sawdust or straw to minimise seepage, odour, flies and rodents (Pittaway NDb, McGahan 1998b, Glanville ND). The pile should be checked daily to ensure that the carcasses are adequately covered to prevent odour nuisance (Pittaway NDb).

Researchers at the University of Missouri suggest minimum primary and secondary heating cycles of 3-6 months, depending on the size of the carcasses to be composted. Segregation of large and small carcasses to separate bays may be helpful (Glanville ND).

- Burial

Burial is a convenient option. However, care must be taken to prevent groundwater contamination in areas where there is porous soil and a shallow water table (Kruger *et al.* 1995). Carcasses also need to be promptly and effectively covered with soil to minimise odours and to not encourage scavenger animals.

- Burning

Burning minimises disease risk since the carcasses are completely destroyed. This is also a simple method and carcasses do not need to be transported far for destruction (Kruger *et al.* 1995). However, burning does create odour and smoke. Fire bans may also pose difficulties.

- Rendering

Rendering converts carcasses into meat and bone meal, meat meal and other products. In the process, it destroys pathogens (Kruger *et al.* 1995). However, it is generally only feasible if the piggery is located very close to a rendering plant.

- Dumping

Some managers dump carcasses out in the paddock and allow them to break-down naturally. This is not a preferred option as it produces odours, attracts scavenger animals and promotes disease transmission.

PHOTOGRAPH 9 – COMPOSTING CARCASSES IN SAWDUST CONFINED WITH HAY BALES

5.14 Methane Generation

The idea of using effluent treatment ponds as methane sources emerged with the energy crisis of the 1970's. A low cost method of collecting methane is to use covered lagoons (refer to section 6.7.2). A more sophisticated, and expensive, method is to use a digester. Full details of the methane generator at Berrybank Farms Piggery is provided in section 7.10.

In summary, Berrybank Farms piggery has installed a Consil Associates Pty Ltd Total Waste Management System, incorporating a methane generator. The effluent is homogenised and filtered and the solids removed pass into a primary, then a secondary digester. Gas produced by the digestion is collected and purified before being used in a cogeneration thermic plant (Heath cited by White 1998).

Wotherspoon cited by White (1998) verifies that the Berrybank Farms plant efficiently extracts methane. Two major environmental benefits are the reduction in the mass of methane released to the atmosphere and the availability of methane for conversion to power.

6 ODOUR AT PIGGERIES

6.1 Odour Nuisance

Odours are a major issue in the Murray Bridge area. Odours from piggeries become an issue when they cause nuisance to neighbours or other receptors. The so-called FIDO factors of frequency, intensity, duration and offensiveness of odour impact define nuisance. Offensiveness includes not only the quality of the odour but also the context in which it is encountered. The translation of the qualitative FIDO factors into quantitative regulations is an extremely difficult task and is not within the scope of this study. However, it is important to understand the factors that cause odour nuisance so that control measures can be proposed. The factors involved in odour nuisance are:

Odour Creation
Odour Emission (release)
Odour Dispersion (source to receptor)
Odour Perception

There is little that can be done to change the perception of odours by neighbours. However, piggery operators have the ability to change odour creation, emission and dispersion.

6.2 Odour Unit Definitions

In this report, odour concentration is expressed odour units (OU). There are numerous odour measurement standards. The longer-term aim in Europe and Australia is to adopt the CEN TC264 standard (or similar) when it is finalised. However, no pig odour studies have yet been conducted using this standard. All good quality data has been collected using the NVN2820 standard or similar. Hence, to avoid any uncertainties caused by an unproven conversion factor, all odour data discussed in this section will be NVN2820.

The odour emission rate from a piggery shed is the odour concentration (OU) times the ventilation rate (m^3/s). Gross odour emission rate has the units of OUm^3/s. In research most studies, the gross emission rate has been normalised to a rate per "pig". However, the definition of "pig" is variously AU, LU, 50-kg liveweight (LWT), SPU, animal place or simply the number of individual pigs. AU and LU are animal units or livestock units respectively and are 500 kg LWT. When this data has been used, it has been converted to 50-kg LWT. A definition of animal place could not be found. In Queensland, the SPU is a unit of measurement for determining the size of a pig production enterprise in terms of its waste output. One SPU produces an equivalent amount of volatile solids to that produced by an average size grower pig (approximately 45 kg LWT). Hence, the units of odour emission from piggery sheds quoted in this report can be OUm^3/s per pig, OUm^3/s per 50-kg LWT or OUm^3/s per SPU depending on the context. The recommendations are given as OUm^3/s per SPU as SPU appears to becoming the accepted regulatory term in Australia.

For ponds, the emission rate is expressed on a unit area basis. Hence, the gross emission rate in OUm^3/s is divided by m^2 to determine the unit area rate of OUm/s for extensive surfaces.

6.3 Creation of Odours at Piggeries

Odours from piggeries are generally the by-products of the anaerobic break-down of organic matter, the exception being volatilisation of ammonia. The organic matter being decomposed is primarily manure (urine and faeces) but can also include spilt feed, afterbirth, carcasses and any other organic matter on-site.

Anaerobic break-down occurs when organic matter is combined with water in the absence of oxygen. It is a two-stage process. The first acid-forming stage converts complex carbohydrates to simpler organic acids (volatile fatty acids (VFA's)). In the second stage, these acids are converted to methane and carbon dioxide. The offensive odours associated with the anaerobic break-down are the VFA's and associated minor, yet offensive, by-products. These gases are most often released when anaerobic break-down is incomplete and second stage (methane formation) does not occur or is incomplete. The most offensive compounds are nitrogen and sulphur based. Comprehensive lists of the compounds found in anaerobic odours created from livestock effluent are given in O'Neill & Phillips (1992), Eaton (1996), Zhu *et al*. (1997a) and Spoelstra (1980). Zhu *et al*. (1999) reviews the role of VFA's in piggery odour.

Aerobic break-down occurs when organic matter is combined with water and sufficient air to support aerobic bacteria. This can occur in both solid (compost) and liquid (aerated lagoon) phases. Under aerobic conditions, the nitrogen compounds in organic matter (proteins, peptides and amino acids) are converted to ammonium (NH_4^+) by heterotrophic bacteria and then oxidised by autotrophic bacteria to nitrite (NO_2^-) and then to nitrate (NO_3^-). Sulphur compounds, i.e. sulphur-containing protein, are converted to sulphate (SO_4^{2-}) in the aerobic environment instead of odorous sulphide and mercaptan compounds in the anaerobic environment. The degree of oxidation depends on the amount of oxygen provided and the reaction time allowed in the treatment process. When aeration is stopped and the dissolved oxygen is depleted, the environment is considered to be anoxic. Under these conditions, nitrate and sulphate function as electron acceptors for facultative bacteria and are thus reduced to nitrogen gas (N_2) and hydrogen sulphide (H_2S) respectively. Generally, aerobic decomposition does not lead to the offensive odours associated with incomplete anaerobic break-down.

Reduction of complex carbohydrates to more stable forms (H_2O, CH_4, CO_2) is a desirable effluent treatment process. Raw effluent has the potential to cause eutrophication of watercourses and other adverse environmental impacts if not treated. Hence, break-down should be promoted in a controlled and complete manner. If not controlled, it will occur in an ad-hoc manner causing odours.

6.4 Odour Sources at Piggeries

Odour can be generated at various sites around a piggery. These include:

- Conventional piggery sheds
- Deep-litter sheds
- Treatment lagoons
- Manure storage areas
- Effluent irrigation areas
- Solid by-product handling and spreading

Given that Smith *et al*. (1999) have estimated that about 80% of all odours from a typical Australian piggery are emitted from the lagoons, then options to reduce primary lagoon surface area should be the first odour reduction strategy examined. These methods include either reduction in size or elimination of lagoons through dry manure handling (deep-litter or dry scraping systems) or the covering or aerating of lagoons.

(It should be noted that this situation is completely different from Europe where van't Klooster and Voermans (1993) estimated that the total odour emissions from an animal facility to the atmosphere is composed of 50% from indoor exhaust air, 25% from manure storage and 25% from manure transport and spreading. Pain (1994) states that, for livestock farms, 27% of odour comes from buildings, 38% from spreading, 22% from manure stores, 10% from feed processing and 3% from silage clamps. As noted in Section 7.1, anaerobic lagoons are more predominant in Australia than any other country.)

The following conclusions about odour generation at piggeries have been taken from Watts (1999a).

6.4.1 Odour Emissions from Conventional Piggery Sheds

Several factors affect the emission of odour from piggery sheds. As these factors often inter-relate, it is sometimes difficult to separate out different factors. However, the following conclusions can be drawn.

Temperature

Several studies report that air temperature is positively correlated with odour emission rate. Emissions are always greater in summer than winter (2-4 times greater). It appears that the most marked increase occurs when internal shed temperatures rise above 25-30°C.

Humidity

Australian data indicates that odour emission rates are positively correlated with in-shed humidity.

Effluent Removal System

Piggeries in Europe, Canada and northern USA typically store effluent in deep pits under the sheds. However, in Australia (and some sections of southern USA), manure is generally flushed out of the sheds1-14 times per week. Regular flushing of manure channels and pits reduces odour emissions compared to the typical deep-pit system. More regular flushing decreases odour emission.

Shed Cleanliness

Increased flushing and hosing results in cleaner sheds and reduced odour emissions.

Diet Composition

Anecdotal information suggests that diet composition effects odour quality and possibly, odour strength. Manure from sorghum-based diets is claimed to smell

worse that manure from barley-based diets. There is no evidence in the literature to support this claim.

Shed Age

Australian research indicates that older sheds emit more odour than new sheds. This may be because older sheds have accumulated manure that is difficult to remove. Alternatively, it may be because older sheds are not designed for frequent flushing and hosing. In this case, shed design (not age) would influence odour emission.

Herd Composition and Shed Stocking Density

The effects of different compositions and shed stocking densities are not clear. Farrowing and weaner sheds are typically designed and managed differently to grower / finisher sheds. Design differences (not animal type) could affect odour emission.

Ventilation Rate

Most studies conclude that there is not a strong relationship between ventilation rate and gross odour emission rate. It appears that when ventilation rate is increased, internal odour concentrations decrease so that the gross emission rate remains constant. This result appears to apply for both mechanically and naturally ventilated sheds. Ventilation rates are generally kept very low at night when mechanical ventilation is stopped and/or side vents are closed. However, no published odour emission rates for very low ventilation rates were found. It seems reasonable to assume that the odour emission rate will not be similar to the daytime emission rate but this needs verification.

6.4.2 Odour Emissions from Deep-litter Sheds

Several factors affect the odour emissions from deep litter sheds. The main factors are:

- Ventilation rate
- Air temperature
- Time of occupation
- Status of the manure / litter mix.

With the current paucity of data, it is difficult to determine an appropriate 'average' emission rate. This is mainly due to the significant variation in odour emission from deep-litter systems as manure accumulates. However, a reasonable long-term average might be 6 OUm^3/s per SPU for a system where the manure / litter mix is maintained in optimal (aerobic) conditions. Hence, when compared with odour emissions from conventional grower / finisher sheds (10-12 OUm^3/s per SPU), deep-litter shelters do appear to offer a reduction in odour emission rate per pig. This advantage would be lost though if poor design and management lead to anaerobic conditions in the litter.

6.4.3 Odour Emissions from Treatment Lagoons

Despite the importance of lagoon odours in the overall odour emissions from Australian piggeries, there has been very little research into lagoon odour levels. The only data available are Schulz and Lim (1993) and Smith *et al*. (1999). Theoretical analyses have been undertaken to extrapolate the limited data to a wider range of wind speeds and stability classes.

Odour emission rate varies with lagoon type and wind speed across the lagoon. Emission rate almost certainly varies with atmospheric stability, although this has yet to be confirmed experimentally.

The variation of odour emission rate with lagoon type is probably driven by lagoon loading rate, lagoon age, microbiological population, sludge accumulation, lagoon chemistry, lagoon temperature and other factors. For example, there is substantial practical experience that suggests that odour emissions from lagoons that support purple-sulphur bacteria ("pink lagoons") (see Photograph 13) are substantially less than black, bubbling anaerobic lagoons (see Photograph 12). We could find no quantitative data on odour emissions from pink lagoons.

The research data available shows that primary treatment lagoons emit more odour than secondary treatment lagoons. A 'typical' standardised odour emission rate from an anaerobic lagoon would be about 30 OUm/s while the emission from a secondary (or tertiary) lagoon would be about 5 OUm/s. The odour emission rate for lagoons whose anaerobic function has been disrupted is probably an order of magnitude higher than a well-functioning lagoon. Hence, it is not surprising that over-loaded or poorly managed anaerobic lagoons are significant sources of odour and give anaerobic lagoons are poor name.

6.4.4 Odour Emissions from other sources

In Australia, lagoons and sheds are regarded as the major odour sources at piggeries. However, odours can be emitted from sources other than sheds and lagoons. These may be categorised as 'permanent' and 'transitory' odour sources.

Permanent odour sources could include screenings mounds, compost piles and manure slurry storage tanks. Transitory odour sources are usually involved with the handling of effluent and include effluent irrigation, land spreading of effluent, de-sludging of lagoons and compost mixing.

Odour data from the UK suggest that the largest, single source of complaints from the public about farm odours arise from the spreading of slurries and manures on land (Pain *et al*. 1991). Hence in Europe, work has been done on the odour emissions from land spreading of stored manure slurry. This is not a common practice in Australia and no work has been done in this area.

6.4.5 Land Spreading of Effluent and Solid By-Products

Pain *et al*. (1991) describe an experiment where odour emissions following spreading of livestock slurries were measured. The livestock slurries were from cattle and pigs. While some parameters are quoted, age and temperature of slurry are not quoted. Ambient air temperatures were in the range of 5°C to 15°C. The researchers do note

that in experiment 1, slurry was withdrawn from the settled layers near the bottom of the store whilst for experiment 2 the upper, more dilute, layer was used. The slurries were spread in a circle and emission rates were determined using the ZINST method. Odour concentration was measured using four dynamic olfactometers. Their construction and operation conformed to "current recommendations" which, in 1987, would not have included panellist screening. Butanol thresholds are not quoted. Emission rates per unit area are not quoted (although they could be calculated). In any event, the uncertain olfactometry means that the absolute data is questionable.

The research indicated that the rate of odour emission decayed exponentially with time between 0 and 60 hr after applying slurry to land. On arable land, incorporating piggery slurry immediately after application by ploughing or rotary harrowing reduced the rate of odour emission for about 5 hr. Only ploughing, immediately after application, markedly reduced total odour emission over 48 hr. Delaying incorporation for 3 to 6 hr after slurry application gave no reduction. Rigid tines had less of any effect than rotary harrowing or ploughing (presumably mouldboard type ploughs).

Phillips *et al*. (1990) and Phillips *et al*. (1991) describe a similar experiment where the odour and ammonia emissions from different types of slurry spreading machines was measured. The first type of experiment, in which a Land Rover equipped with a sampling frame followed behind a spreader, compared emissions arising during spreading. For ammonia emissions, a low-trajectory spreader, a shallow injector (75 mm) and a deep injector (150 mm) all gave significantly lower emissions than did a conventional spreader, but a light-weight irrigator gave higher emissions. However, for odour, because the standard errors of the measurements were greater than for ammonia, there were hardly significant differences between the machines.

The second type of experiment, which used a micrometeorological technique based on large circular plots (ZINST), compared emissions after spreading, when the slurry was lying on the ground. A low-trajectory spreader gave some reduction in odour emission compared with a conventional spreader, although both shallow and deep injection gave a much greater reduction. The emissions per m^3 of slurry spread were many-fold less during spreading than after spreading, with the former being less than 1% of the latter.

Pain *et al.* (1990) describe a similar experiment to measure odour and ammonia emissions following the spreading of aerobically-treated piggery slurry on grassland. Unseparated and separated slurries and two aerobically-treated slurries were applied to grassland plots. A system of small wind tunnels was used in the collection of odorous air samples and in the measurement of ammonia volatilisation. Separation alone gave a 26% reduction in total odour emission. Both aerobic treatments reduced the total odour emission over 52 h by 55% compared with no treatment. Aerobic treatment also reduced odour intensity and odour offensiveness. Both aerobic treatments also increased slurry pH, which lead to an increase in the total loss of N through ammonia volatilisation after spreading on land.

In a similar experiment, Pain and Misselbrook (1991) researched the effect of spreading piggery slurries on odour and ammonia emissions. They found a significant correlation between odour and ammonia emissions when untreated piggery slurries were spread. A strong, positive linear relationship was found between odour and ammonia emissions following application of untreated piggery slurries, although the slopes of the regression lines differed in different experiments. No such correlation was obtained for treated slurries. Thus treatments designed to

reduce odour emission would not necessarily reduce ammonia emission, and vice versa.

6.4.6 Manure Slurries and Slurry Tanks

In Europe, a number of studies have examined the odour and ammonia emissions from manure slurries and manure slurry tanks. This data is of limited use in Australia because:

- Storage of manure as an untreated slurry is uncommon.
- Manure slurry storage occurs at much lower temperatures than would be applicable in Australia. Hence, manure breakdown characteristics would be significantly different.

6.4.7 Compost

Composting of various solid by-products (screenings, lagoon sludge, and pig carcasses) is becoming more popular. As environmental pressures increase, there is every expectation that more composting will occur. While little odour is emitted from well-managed aerobic compost heaps, it is also clear that significant odours can be emitted from poorly-managed, anaerobic compost. There is ample experience of this from the mushroom industry.

We could find no quantitative published data on odour emissions from composting.

6.5 Odour Minimisation

6.5.1 Odour Minimisation concepts

In principle, odours at piggeries can be minimised if anaerobic conditions are minimised or if complete, controlled anaerobic break-down occurs. Hence, conceptually, odour minimisation techniques include the following.

- Keep organic by-products dry
- Reduce the quantity of effluent
- Reduce the nitrogen and sulphur content of effluent
- Keep by-product organic matter aerated
- Ensure complete controlled anaerobic processes
- Adopt aerobic organic matter reduction methods

Specifically, these odour minimisation techniques can be achieved at a piggery by:

- Diet modification to reduce the amount of manure produced
- Diet modification to reduce the nitrogen and sulphur content of manure
- Addition of proprietary additives to the diet or treatment system to modify break-down
- Reduction in feed wastage/prevent waste feed from entering the effluent stream
- Dry handling of manure (dry scraping of manure, deep-litter systems)
- Aerobic treatment of effluent and solid by-products (aerated lagoons, aerobic composting)

- Improved anaerobic digestion methods (high-technology digesters).

6.5.2 Diet Modification

There are two ways in which diet modification can potentially reduce odour. Firstly, more digestible diets result in reduced manure production (and consequently odour when the manure decomposes). In beef cattle lot feeding, steam flaking of grain improves the digestibility of starches and reduces the amount of undigested starch in manure. This leads to reduced odour. Improving the conversion of feed can not only reduce odour but also lower feed costs, which represent about 60% of production costs (Swine Odor Task Force, 1995). Secondly, alterations to the chemical composition of the diet should change the character of any odour subsequently produced.

Examples of work on the effect of diet modification on odour (and ammonia) release include Cromwell (1996), Clanton *et al*. (1991), Kellems *et al*. (1979), Sutton *et al*. (1996), Sutton *et al*. (1997) and Sutton *et al*. (1998).

Because nitrogen is a key ingredient of ammonia and many other odorous compounds, it is generally true that the higher the nitrogen content of pig manure, the greater its potential odour (Swine Odor Task Force, 1995). In general, pigs excrete excess nitrogen when they ingest more protein than they can efficiently use. In Europe, there is considerable pressure to reduce nitrogen output in manure and much research has been undertaken on low nitrogen diets (e.g. Jongbloed and Lenis, 1992, Misselbrook *et al*., 1997, Kaye and Lee, 1997, van der Peet-Schwering and Verdoes, 1998).

Van der Peet-Schwering and Verdoes (1998) describe two experiments that were conducted to investigate the effect of feeding low-protein diets in combination with simple housing measures on the ammonia and odour emission and performance of growing and finishing pigs. Phase-fed fatteners in an optimised pen design produced 55% less odour than control pigs. The odour emission during the summer period was higher than during the winter period.

Kaye and Lee (1997) investigated the effect of reduced protein diets fed to growing and finishing pigs on ammonia emissions from the sheds and nitrogen losses from the slurries produced. They found that the volume of slurry produced by the pigs declined by 28% and ammonia emissions declined by 58% and 46% for grower and finisher pigs, respectively.

Research on feed conversion efficiency and its impact on odour has progressed in several directions:

1. Amino acids. In Europe, researchers have extensively studied methods to reduce nitrogen excretion by pigs. In most studies, this has involved substituting synthetic amino acids for traditional protein sources.

2. Digestibility of protein. Studies in North Carolina and elsewhere have demonstrated that protein digestibility can be improved by better processing techniques. The use of proteolytic enzymes in processing or as dietary supplements can also increase protein digestibility.

3. Odour absorbers. There are numerous reports about dietary supplements such as calcium bentonite, zeolite, sagebrush and charcoal. All of these additives adsorb odour-causing compounds such as ammonia. However, feeding these compounds to pigs at the levels required for reducing odour, may also reduce growth or the efficiency of feed conversion.

4. Sarsaponin, enzymes, and microbials. Some of the most promising feed additives are plant extracts, enzymes, and direct-fed microbials, all of which may help control odour and improve growth performance in animals. Research indicates that sarsaponin, a natural extract from the yucca plant, can reduce ammonia and promote beneficial microbial action in pits and lagoons. In some studies, mixing sarsaponin with pig feed has also increased weight gains and improved feed conversion.

Sarsaponin's mode of action is yet to be established. Some studies indicate that the compound inhibits urease or promotes microbial growth. There is also evidence that sarsaponin removes ammonia, which is toxic to many microbes, converting the ammonia nitrogen into microbial protein. Sarsaponin may condition microbial cell membranes and reduce surface tension, increasing the absorption of nutrients across cell membranes and promoting microbial growth. Because sarsaponin passes unabsorbed through the animal, it provides a simple, indirect means of treating bedding and the contents of lagoons.

Several other supplemental enzymes, probiotics (direct-fed microbials), and bacteria may also reduce odours in piggeries. Much more research is necessary to evaluate the potential and practicality of each of these kinds of additives (Swine Odor Task Force 1995).

Unfortunately, some additives currently used may actually increase the odour of manure. Antibiotics and certain growth promotants, such as arsenic and copper, inhibit microbes not only in the gut of the animal, but also in its manure, retarding the microbial digestion of odorous compounds. This would be a concern primarily in liquid-based effluent treatment systems.

6.5.3 Odour Control Additives

There are many different commercial products that claim to reduce odours from piggeries. In most cases, there has either been no scientific testing of the products or the scientific tests have been inconclusive. Although some piggery operators are convinced of their effectiveness, there is not sufficient data to justify their recommendation as an odour control option.

Most of these products are found in one of the following categories (Swine Odor Task Force 1995):

1. Masking agents are mixtures of aromatic oils used to cover an objectionable odour with a more desirable one.

2. Counteractants are aromatic oils that cancel or neutralise an odour so that the intensity of the mixture is less than that of it constituents.

3. Digestive deodorants contain bacteria or enzymes that eliminate odours through biochemical digestive processes. For example, sarsaponin promotes microbial action.

4. Adsorbents are products with a large surface area that adsorb the odours before they are released to the environment. Sphagnum peat moss, for example, has reduced odour for some lagoons.

5. Chemical deodorants are strong oxidising agents or germicides. Germicides such as orthodichlorobenzene chlorine, formaldehyde, and paraformaldehyde alter or eliminate bacterial action responsible for odour production. Oxidising agents such as hydrogen peroxide, potassium permanganate, and ozone chemically oxidise odour-causing compounds.

Each of these groups has its strengths and limitations. Masking agents and counteractants, for instance, can be effective in the short-term storage of organic by-products. However, because these products typically are organic compounds that can be broken down by bacteria, most of them quickly lose their effectiveness in lagoons and tanks.

Aggressive marketing in the USA has increased the use of digestive deodorants. These products, which contain enzymes or bacteria or both, are advertised for their abilities to break down solids, reduce the release of ammonia, and conserve nitrogen. No single product can affect all of the odour-causing compounds in pig manure. However, unless the environments of lagoons and other effluent-treatment systems are favourable, supplemental bacteria may die off or fail to reach sufficient numbers to control odour. Of the many products tested in the Netherlands and in Germany for their ability to reduce odours from manure slurries, none has proven reliably effective.

Some additives reduce odour by altering the volatility of odorous compounds. Lime, for example, not only inactivates compounds such as hydrogen sulphide but also increases the amount of ammonia released from manure. Because of an emphasis on reducing ammonia, research in Europe has focused on acidifying agents. Studies indicate that applications of lactic acid bacteria can maintain the pH of manure at 6.4, reducing ammonia emissions by as much as 80% during storage and application. Because this process also retains nitrogen in the effluent, there is much more nitrogen applied to land than is the case with lagoon-based systems.

In general, the results of scientific research on the effectiveness of odour control additives have been inconclusive. For example:

Zhu *et al*. (1997b) state that “to date, there have been hundreds of commercial pit additive products in the market. However, most of these products were proved to be ineffective in controlling swine manure odor". They also say that evaluation methods for additives should be improved and standardised.

For manure storage tanks, Patni and Jui (1993) tested a number of odour control additives. They found that none were effective in reducing the escape of odorous gases nor in changing the nature of the residual sludge except for the addition of peat moss which formed an intact scum layer on the top of the storage tank (This is effectively a biofilter – see Section 6.6.3).

Amon *et al*. (1995) studied De-odorase, which is a Yucca extract. De-odorase proved helpful in reducing ammonia levels in piggeries but had no effect on odour

levels and livestock productivity. They stated that "neither odour concentration nor odour emission rate was significantly reduced through the use of the additive".

Pattison (1999) examined the effectiveness of various odour control additives in a deep-litter system in Victoria. The following treatments were investigated:

1. Control - standard diet and conditions
2. 5% zeolite in standard diet
3. Zeolite spread at 2.5 kg/m^2 every 2 weeks
4. 5% zeolite in diet, zeolite spread at 2.5 kg/m^2 every 2 weeks
5. 0.1% actigest in standard diet (or manufacturers recommended application rate)
6. Actigest in diet plus actizyme spray in shed (or manufacturers recommended rate)
7. 100 ppm yucca extract (biosaponin) in standard diet
8. Qweller spray application to litter and shed (manufacturers recommended rate)
9. Epolean spray (manufacturers recommended rate)
10. Actizyme spray application to litter and shed (manufacturers recommended rate)
11. Holistic diet with minimal nitrogen to meet requirements and very high DE content
12. Rotary hoe deep litter every two weeks to stimulate composting
13. Zeolite floor application to litter and rotary hoe every two weeks

The treatments were measured in lots of two against a control. Hence, the experiment took some time to complete. The mean shed temperatures ranged from 16.6 °C to 25.8 °C. Relative humidity ranged from 50.2% to 84.4%.

The effect of season on odour emission rates overshadowed the value of individual odour amelioration treatments. Ranking of absolute odour emission rates and of odour emission rates relative to the treatment control are shown in Table 2. These comparisons suggest that Actigest in the diet, zeolite in the diet and aeration of the litter by rotary hoe resulted in substantial reduction in odour emission. This research indicated that the other treatments provided little benefit. The addition of zeolite to the floor without rotary hoe appeared to have an adverse effect on odour emission rate, possibly because increased moisture was stored, there was accelerated waterlogging and anaerobic breakdown occurred.

Actigest contains several probiotic, bacillus strains of bacteria and added enzymes. It is intended to increase the digestion of feed and changes the fermentation patterns of digestion both within pigs and in the faeces subsequently voided. The expected end result is improved animal performance and reduced odour emission. The fastest growth rate was observed in the combined Actigest and Actizyme treatment. Addition of zeolite to the diet also appeared to decrease odour emission. Zeolites reduce ammonia and odour emission threshold concentrations in piggeries. It is assumed that addition of zeolite to diets reduces the absorption of ammonia, binds micro-organisms and reduces the water content of faeces. The faeces from pigs in zeolite treatments appeared to be more friable and it is possible that this allowed more aerobic degradation of faecal organic matter. Both rotary hoe treatments also reduced odour emission to about 40% of the control sheds. These treatments increased aeration and composting of the litter. Aeration and reduced moisture content of animal manure reduces odour emission by encouraging aerobic breakdown of organic compounds.

Despite these apparent advantages of Actigest and zeolite, combining these treatments with others did not cause the same substantial reduction in odour emission. The combined treatment of Actigest and Actizyme spray resulted in a one-

fold reduction in odour emission compared with a ten-fold reduction with Actigest alone. Similarly, the combined treatment of zeolite in the diet and on the floor was not as effective at reducing odour as zeolite in the diet alone. However, there was some evidence that zeolite added to the floor increased the water content and anaerobic condition of the litter. Because the treatments were not replicated and because the extent of saturation of the litter between sheds varied, it is difficult to be confident that certain treatments will reduce the odour emission rates. The lack of effect of the fragrant and surfactant containing compounds is not surprising given the high odour emission rates from the sheds.

TABLE 2 - RANKING OF EFFECTIVENESS OF ODOUR AMELIORATION TREATMENTS

(Pattison 1999)

Treatment Rank	Odour emission Rate (OU m^3/s)	Treatment Rank	Odour emission rate relative to control
1. Actigest: diet & spray	1,093	1. Actigest: diet	0.12
2. Rotary hoe: zeolite	1,295	2. Zeolite diet	0.31
3. Actigest: diet	1,338	3. Rotary hoe: zeolite	0.37
4. Rotary hoe	1,377	4. Rotary hoe	0.39
5. Qweller spray	1,519	5. Actigest: diet & spray	0.52
6. Holistic diet	1,746	6. Epolean spray	0.71
7. Actizyme spray	1,959	7. Qweller spray	0.72
8. Control 3-1, 26 Oct.	2,030	8. Holistic diet	0.86
9. Control 4-7, 6 Oct.	2,112	9. Actizyme spray	0.97
10. Control 3-1, 25 Aug.	2,160	10. Zeolite: floor & diet	1.04
11. Control 2-1, 11 Nov.	3,529	11. Biosaponin	2.70
12. Biosaponin	5,832	12. Zeolite: floor	9.05
13. Zeolite: diet	6,706		
14. Epolean spray	7,654		
15. Control 2-7 8 Sep.	10,788		
16. Zeolite: floor	19,543		
17. Control 4-1, 18 Aug.	21,739		
18. Zeolite: floor & diet	22,689		

6.5.4 Oligolysis

Oligolysis is an odour control technique that has been researched by a group in Canada for a number of years (Yu *et al*. 1988, Yu *et al*. 1989, Yu *et al.* 1991, Coleman and Goodwin 1992, Coleman *et al*. 1993, Wang *et al*. 1994, Feddes *et al*. 1998).

Oligolysis is claimed to effectively reduce H_2S evolution and odour from anaerobic digestion of pig manure. According to Chiumenti *et al*. (1988) the energy requirements for oligolysis were 4-5% of the requirements for an aeration treatment that would achieve the same level of odour reduction. Furthermore, oligolysis does not appear to interfere with the microbial activity during digestion of the stored pig manure.

In oligolysis, odour and sulphide reduction is achieved by an electro-chemical process similar to that of electrolysis. Two electrodes are immersed in the slurry and a voltage is applied across the electrodes. The electrical potential causes ferrous ions (Fe^{2+}) to be released by the anode in the slurry to form ferrous sulphide (FeS), an insoluble precipitate. Hence, the free S^{2-} are prevented from participating in chemical and biological reactions that would otherwise lead to the formation of odorous compounds such as H_2S. The voltage applied across the electrodes significantly influences the oligolysis process. The level applied is dependent on the electronegative potential required for the oxidation of iron, the electrical conductivity of the slurry, and the surface area and spacing of the electrodes (Feddes *et al*. 1998). All of the work on oligolysis seems to have been conducted at the laboratory level. It appears that there are no practical applications of the method to date.

6.5.5 Dry Handling of Manure

Given that most odours result from wet manure (anaerobic conditions), odour reduction should occur if manure and other by-products can be kept dry.

The most obvious application of this principle is the deep-litter housing system (see Section 5.10). This pig production system has increased in popularity in Australia in the last five years, mainly due to the low capital cost. However, there are also environmental advantages with dry manure handling. It is claimed that these structures have little odour compared with conventional pig housing.

Another application of dry handling of manure is dry scraping of manure from conventional sheds (see Section 5.9). In this approach, conventional housing can be used but with dry scraping of the manure from the sheds, rather than flushing. Solid manure can then be composted and spread on land. Hence, large treatment lagoons are not required. This method is not used widely. There are two piggeries in South Australia that use this approach (Robert Fielke at Loxton and Graeme and Pat Mee at Waikerie) and there are some piggeries in New Zealand (Burnalan and Bardfield) that have also used dry scraping. No odour emission data is available for dry scraping systems.

6.6 Odour Modification

6.6.1 Odour Modification Concepts

Treatment of effluent prior to it's release to the atmosphere may reduce offensive odours. Treatment can include biological methods or chemical methods. Most odours are produced in the piggery buildings and treatment lagoons. Biological treatment of shed odours can be achieved by passing the odorous air through a biofilter. Biological treatment of anaerobic lagoon odours can include aerating the surface layer (to encourage aerobic microorganisms), encouraging purple sulphur bacteria or covering the lagoon with a biofilter. In all these cases, the emitted cases are treated but are not confined. The treated non-odorous gases (including methane and carbon dioxide) are released to the atmosphere. Chemical treatment can include ozone addition.

6.6.2 Biofilters for Sheds

Biofilters are devices where odorous air is passed through a porous media before release to the atmosphere. The porous media can be soil, peat, sawdust or compost. The biofiltration process involves bacteria and fungi that live on the media surface. As the exhaust air passes by this biofilm on the media, the bacteria eat or oxidise the odorous gases. Therefore, a biofilter is not like a dust filter that fills up and must be cleaned. Instead, it is a living ecosystem of microorganisms that continually feed on odorous gases. To support this living ecosystem, a biofilter needs the correct moisture content, oxygen level, temperature, and food source to stay alive. The microorganisms oxidise the complex odorous compounds and convert them to less harmful products such as water, carbon dioxide and inorganic salts. Biofilters have been used for over 20 years to reduce odours from rendering plants, compost facilities and other industrial activities. Figure 7 shows a schematic layout of a biofilter.

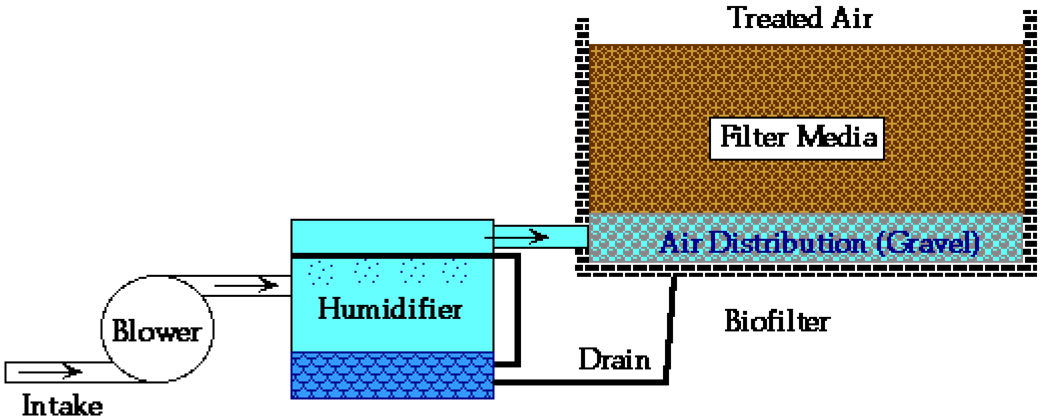


FIGURE 7 – SCHEMATIC LAYER OF A BIOFILTER

A number of researchers have examined the application of biofilters to piggery sheds. They include Noren (1985), Zeisig (1987), Klarenbeek (1993a, 1993b, 1995a, 1995b), Young *et al*. (1997a, 1997b), Hartung *et al*. (1997), Hartung *et al*. (1998), Nicolai and Janni (1997a, 1997b), Nicolai (1998), Nicolai and Janni (1998a, 1998b), Lais *et al*. (1997), Hoff *et al*. (1997), Hoff *et al*. (1998), Siemers and van den Weghe (1997), Dong *et al*. (1997). Sweeten *et al.* (1991) used a soil biofilter to successfully scrub air from a poultry manure composting operation.

Figure 8 illustrates the various parts of a biofilter for mechanically-ventilated livestock facilities (Noren, 1985 taken from Nicolai 1998). It consists of:

1. A mechanically-ventilated structure that can control gaseous emissions.
2. An exhaust fan system to move the air through the building (and above the manure storage) and through the biofilter.
3. An air duct system to bring the air to the biofilter air plenum.
4. An air plenum to distribute the exhaust air evenly beneath the biofilter media.
5. A media support structure component that supports the media above the air plenum and has a minimum of 35% opening for air to pass through without causing a high back pressure for the exhaust fan.
6. Biofilter media to serve as a surface for microorganisms to live on. The spacing between these biofilter media surfaces is important, both for the passage of exhaust air and to provide area for bacterial growth.

For a biofilter to operate efficiently, the media must provide a suitable environment in which microorganisms can live and reproduce, have good moisture holding capacity, and have a high porosity for minimal back pressure. The media should be locally available for acceptable construction costs. Critical properties of each material type include (1) porosity, (2) moisture holding capacity, (3) nutrient content, and (4) useful life before the material decomposes. These properties affect the following operating parameters: (1) pressure drop, (2) airflow rate, (3) moisture addition, and (4) pH buffering. Peat, loam soil, straw, sawdust and compost normally contain sufficient microorganisms to start up a biofilter. Nicolai (1998) provides design data for a biofilter.

The performance of biofilters is measured by the %age reduction in odour concentration of outgoing air compared to incoming air. Odour reductions of 50% to 90% are reported in the literature.

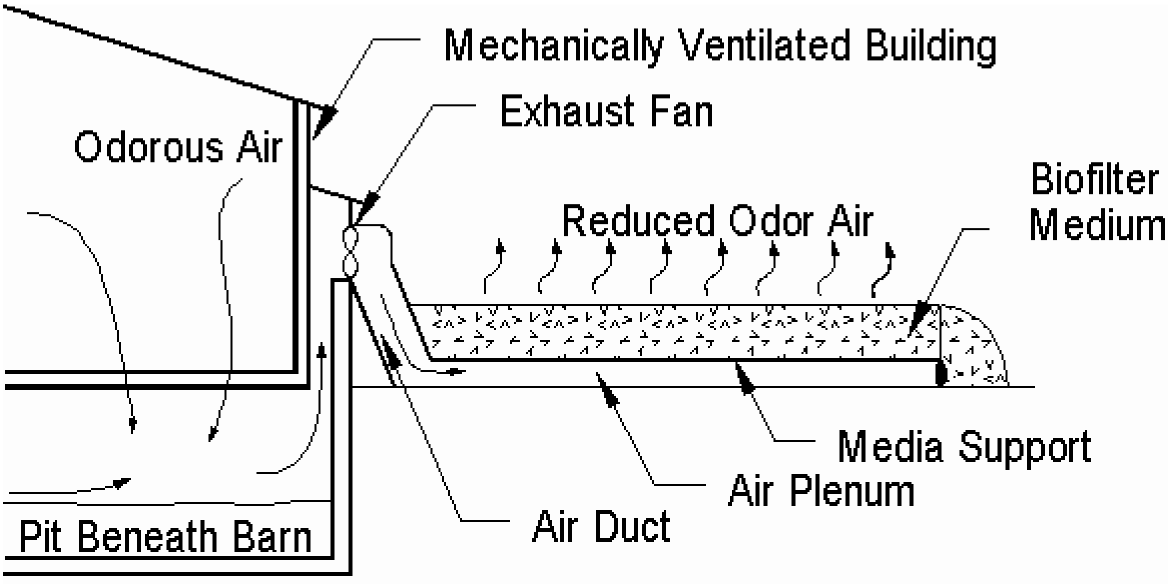


FIGURE 8 – BIOFILTER ATTACHED TO PIGGERY SHED

(taken from Nicolai 1998)

Experience with biofilters in Europe, the US and elsewhere has shown that they can be very effective in removing odours from livestock building airflow, but challenging in terms of cost and management. For example, Minnesota researchers used a biofilter to clean air being pulled through a manure pit fan at a piggery building. They minimised system costs by using existing materials, such as kidney bean straw and inexpensive materials to build the filter. Some 75-90% of the odour was removed at a relatively low resistance to airflow. At North Carolina State University, tests of three identical biofilters also showed they were effective in reducing odours from a piggery building manure pit.

In another biofilter study in Minnesota odour at a 700-sow gestation/farrowing swine facility was reduced by 95% and hydrogen sulphide by 90%. The amortised cost of biofilter construction and operating cost for three years was $0.22 per piglet produced. Included in construction and operating costs were increased fan power for higher pressure, air ducts, structural support for the biofilter media, the biofilter media and a sprinkler system to wet the media.

Biofilters may work well at low ventilation airflow rates. However, air must be detained in the filter for 5 to 10 seconds for the filter to be effective. A biofilter properly sized for high summer ventilation rates would be extremely expensive. Estimates of biofilter costs for cleaning all the airflow from swine buildings in warm weather have exceeded $200 per pig space. Since biofilters work best with very odorous air (rather than the more dilute air typical of high summer ventilation rates), it may be that biofilters can be used as a cool weather system, with a different system for treating odorous air in warm weather.

To remove the odorous dust from piggery building airflow without the expense or resistance of biofilters, researchers at Iowa State University have been testing biomass filters. Airflow from a pig nursery building is directed through or over beds of chopped corn stalks and corn cobs. No attempt is made to wet the biomass to maintain a population of microorganisms, as is the case with biofilters. A biomass filter removes odorous dust from the air stream using inexpensive material. In one configuration, air is moved through three-tiered, 6-inch thick beds of biomass. In another configuration, a series of vertical panels made from wooden 2 x 4 frames filled with biomass are arranged to force the airflow around the biomass, removing odorous dust. Both systems reduced odour and dust levels significantly (up to 90% reduction of odour and 80 % reduction of dust). These reductions occurred with low resistance to airflow at cold weather ventilation rates. Biomass filter research is encouraging. It remains to be seen, however, whether biomass filter systems can be designed for ease of biomass cleaning or replacement and to accommodate the higher ventilation rates needed in warm weather. (Board of Governors, University of Carolina, 1998)

Biofilters attached to piggery sheds are probably not a best-bet solution for odour problems at Australian piggeries. This is because:

- Most Australian sheds are naturally ventilated. There would be substantial capital and operating cost increases for Australian sheds to be fully enclosed and mechanically ventilated.

- In Australia, the odour emissions from sheds are only 10%-30% of all odour emissions at a piggery. Hence, the most effort and expense should go into reducing odours from lagoons or eliminating lagoons.

6.6.3 Biofilters for Lagoons

Lagoon (and manure slurry store) covers can be categorised as follows.

- Inorganic permeable covers
- Organic permeable covers
- Impermeable covers

Inorganic, permeable cover materials found in the literature include artificial rock (Li *et al.*, 1997, Bundy *et al.* 1997), floating mesh, film (Li *et al.*, 1997, Bundy *et al.* 1997), polyethylene foam, zeolites (Miner and Pan 1995, Miner and Suh 1997), waste crankcase oil (Meyer and Converse 1982), corrugated plastic-coated steel (Williams and Nigro, 1997) and Permalon (Clanton *et al.* 1997).

Although Miner and Pan (1995) and Miner and Suh (1997) claim that their inorganic materials allowed a biological media to develop, most of these coverings simply

reduce the rate of odour loss through a reduction in the exposed liquid area available for gas transfer. They do not act as biofilters. Also, the long-term environmental consequences of the use of some of these materials are questionable.

Organic permeable cover materials found in the literature include chopped straw (Meyer and Converse 1982, Li *et al.* 1997, McMahon 1996, Bundy *et al*. 1997, Filson *et al*. 1996), corn stalks (Meyer and Converse 1982, Li *et al.*, 1997, Bundy *et al*. 1997), wood shavings (Meyer and Converse 1982), rice hulls (Meyer and Converse 1982) and sawdust (Meyer and Converse 1982).

Although these covers often reduce odour by up to 90%, an on-going problem with organic cover materials is durability. Many materials breakdown, blow to one side of the lagoon or sink. There may be a role for some form of inorganic material to support the organic biofilter media.

Extensive work on the use of organic lagoon coverings as a biofilter has been undertaken in Canada (Filson *et al*. 1996, Alberta Agriculture 1997, PAMI 1993). The following information is from http://www.agric.gov.ab.ca/esb/afmrc/698.html.

In 1992, PAMI concluded a series of five projects to develop coverings for piggery manure lagoons that effectively controlled odours. The effectiveness of supported and unsupported covers were investigated, particularly cover durability, straw type, odour reduction period, and management problems. In the final project, several straw types were used in full-scale tests on lagoons. PAMI conducted detailed tests using straw covering systems on four lagoons located at Abernethy, Lucky Lake, Spalding, and Humboldt. Observations were also made on covers applied by a commercial contractor at four sites near Spiritwood. Studies were done to determine:

- performance of various straw types and qualities
- performance of artificial flotation devices for straw support
- performance of a shredder/blower device for straw application onto lagoons
- problems during lagoon pump-out, caused by straw or flotation devices
- costs of straw covering systems for lagoons.

For both flotation-supported covers and non-supported covers, straw was applied using a device designed to spread straw for surface erosion control in road construction. The applicator consists of a conveyor moving square bales through a flail shredder into a paddle fan blower which blows the straw through a moveable spout.

Two flotation devices under the straw layer were tested; polystyrene sheets 25 mm thick (Photograph 10), and plastic engine oil bottles (Photograph 11). They were simply dumped onto the lagoon and allowed to drift into position to provide a uniform covering of the liquid surface. A floating barrier was used to keep them in the liquid cell of a two-cell lagoon.

Good quality barley straw was the only effective material for unsupported covers. Odour control was excellent as long as the straw floated and was dry on top. To be considered of good quality, the straw should be fresh, unweathered, and relatively dry, with as many whole stalks as possible. The tubular stalks act as flotation devices, and surface life is reduced if stalks are shredded or shattered. Barley straw can give effective odour control over the entire season, with only one or two reapplications to small areas of the lagoon surface to recover areas of straw sinkage.

The polystyrene floats kept the straw cover supported and dry for nearly the entire season, with excellent odour control. Since the cover floats downwards at pump-out and back to the surface on refill, multiple-year usage of the floats is possible. Reapplication of straw may be required each year to repair damaged areas. Oil bottle support systems worked well. However, a number of bottles leaked and sank because their caps were not properly tightened. Tightening of individual caps would be necessary to ensure best performance.

It is important that this work is viewed in terms of the climate. In Saskatchewan, straw only needs to be applied in the early-June to late-August or early-September time frame. Manure storage areas are frozen over from November to mid-April, thus negating the need for any remedial action during the winter months. In most cases, manure storages are emptied in late-September to late-October and the cooler weather in May and September helps to reduce odour problems at these times. Barley straw will start to sink after 2 to 3 weeks. Areas of open liquid will start to appear after 4 to 6 weeks and the odour problem is considered to be significant once 15% of the manure storage area is open. One reapplication of straw is all that is required to control the problem before weather again intervenes.

Clearly this system would not produce year-round results in Australia. However, the work does show that low-cost straw covers can act as a biofilter and thus control odours from anaerobic lagoons. The practical problem of maintaining a dry straw cover (150 – 300 mm thick) over the lagoon year-round needs to be solved for adoption in Australia. Some form of mesh structure or geotextile supported above the liquid surface onto which straw could be spread is required. The problems associated with heavy rain and strong wind also need resolution.

In Queensland, the Department of Primary Industries (DPI) has commenced a study of the use of organic lagoon covers. The first stage will be laboratory scale studies and, based on these results, field trials will be undertaken. No data are available yet.

Another form of treatment lagoon biofilter is the solution found (by chance) in many abattoirs. This is the thick, solid, floating layer of fat that forms over the primary anaerobic lagoon. These crusts act as very effective biofilters. They do not form in piggeries, as there is little fat (oil and grease) in the effluent stream. However, fat removed from an abattoir's DAF system could be placed over a piggery lagoon to form a thick, floating layer that would act as a biofilter.

Impermeable lagoon covers are designed to completely trap all gases emitted during the anaerobic breakdown process. The captured gas can either be flared or used as an energy source. These types of covers will be discussed in Section 6.7.2.

Photograph 10 - Polystyrene Floats in Place on a Lagoon

(taken from PAMI 1993)

Photograph 11 – Applying Straw onto Oil Bottle Floats on a Lagoon

(taken from PAMI 1993)

6.6.4 Surface Aeration of Lagoons

Naturally aerobic lagoons (i.e. without mechanical aeration) are rarely economically practical for piggeries because as they require very large surface areas – as much as 25 times more surface area and 10 times more volume than a 3 m deep anaerobic lagoon (Westerman and Zhang, 1997). They estimate that a farrow-to-finish piggery would require 340 m^2 of lagoon surface per sow.

Surface aeration of anaerobic treatment lagoons has been investigated by a number of researchers and seems worthy of further examination. The aim of surface aeration is to form an aerobic blanket over the top of an anaerobic lagoon. Under aerobic conditions, the nitrogen compounds (proteins, peptides, amino acids, amines) are first converted to ammonium by heterotrophic bacteria and then oxidised by autotrophic bacteria to nitrite and then to nitrate in the aerobic environment. Sulphur compounds (sulphur-containing proteins, mercaptans, sulphides) in the effluent are converted to elemental sulphur or sulphate which prevents the formation and emission of odour-causing sulphide and mercaptan compounds. Hence, an aerobic surface layer can convert the odorous compounds rising from deep within an anaerobic lagoon to non-odorous gases or precipitates.

Examples of this approach are Barth and Polkowski (1971), Ginnivan (1983), Zhang (1996a), Zhang *et al.* (1996), Zhang *et al.* (1997), Schulz and Barnes (1990), Heber (1988) and Overcash *et al*. (1976).

Heber (1998) showed that a surface-aerated first-stage lagoon emitted 82% less odour than similar non-aerated lagoons with only half of the volumetric loading rates. Odour emission rates with simulated wind speeds of 1.1 m/s in a buoyant flux chamber (0.76 m^2) ranged from 89 to 123 OU/min-m^2 and averaged 100 OU/min-m^2. (This is only 1.66 OU/m^2-s). Volatile solids (VS) loading rates are given. The surface aerated lagoon had a loading rate of 96 gVS/m^3-day while the two non-aerated lagoons had loading rates of 80 and 51 gVS/m^3-day. These loading rates are similar to the recommended rates for anaerobic lagoons at Australian piggeries. The total odour emission rate from 9720 m^2 surface-aerated first-stage lagoon would be 16,163 OU/s.

Zhang *et al*. (1996) and Zhang *et al.* (1997) studied surface aeration in the laboratory. Surface aeration of anaerobic lagoons for odour control was experimentally studied with laboratory reactors used to treat pig manure. The effects of different aeration rates and depths on reduction in emissions of odours and ammonia and sulphur gases were evaluated for both continuous and intermittent aeration. Odour concentrations above the surface reduced from about 1200 OU to 30 OU when surface aeration was applied. It is concluded that surface aeration is effective for controlling odours in anaerobic lagoons. Low rate and continuous aeration to maintain dissolved oxygen in the top liquid layer (300 mm) at 0.5 mg/L is sufficient for effective odour control but may result in high ammonia emissions. Intermittent surface aeration proved to be a feasible strategy for minimising energy usage.

Schulz and Barnes (1990) investigated the effect of surface aeration of anaerobic lagoons. They called the concept the stratified lagoon system. The system was tested at a 3000-sow piggery near Sydney. The piggery had underfloor channel flushing into a run-down screen for solids removal prior to the anaerobic lagoon. The lagoon capacity was 23,000 m^3 (about 0.8 m^3/pig) with a depth of 5.5 m. The surface of the lagoon was mechanically aerated. The energy input was about 2 W/m^3 of

lagoon volume. The aerators were arranged so that a horizontal circulation was established on the lagoon surface. It was claimed, although not supported with olfactometry, that odour levels were considerably lower than without the aeration.

For surface aeration, good design of the aeration system is essential. The objective is to only aerate the top 300 mm with minimum energy usage and to not mix deeper layers (and their sediments) with the surface layer. The practical design aspects of surface aeration need to be solved before this system can be widely recommended.

The data contained in the literature is insufficient to be able to recommend odour emission rates applicable to surface-aerated lagoons.

6.6.5 Purple Sulphur Bacteria

Many piggery operators are familiar with purple sulphur bacteria, even if they have never heard the term. Purple sulphur bacteria live in the surface layers of lagoons and change the effluent colour to a dirty red-brown, vivid pink or dark purple depending on their prevalence (see Photograph 13 compared to Photograph 12). Considerable anecdotal evidence exists that says that a pink lagoon is a low-odour lagoon. Some producers strive to achieve pink lagoons for this reason.

Purple sulphur bacteria are phototropic. In the presence of light and under anaerobic conditions, they oxidise hydrogen sulphide. The end oxidation product is sulphate. Carbon dioxide and simple organic compounds are used as carbon sources in the photosynthetic process (Schulte *et al*. 1997).

The design and management factors that encourage the growth of purple sulphur bacteria are poorly understood. Schulte *et al*. (1997) studied eight piggery lagoons during the spring and summer of 1996 to try to find the factors that encouraged bacteria growth. Many variables were measured but none were shown to be clearly linked to bacteria growth. Popular opinion suggests that purple sulphur bacteria are more likely to appear in lightly-loaded lagoons. However, the researchers found that the bacteria occurred in one of the most heavily loaded lagoons (130 g VS/m^3/day).

Gebriel *et al*. (1999) undertook experiments to determine which factors affected the growth of purple sulphur bacteria. Figure 9 shows their representation of the growth of purple sulphur bacteria. Their report provides a good literature review of the bacteria. However, they did not provide findings that give clear guidance on design or management factors that encourage bacteria growth.

Given the clear (but unmeasured) benefits of odour reduction when purple sulphur bacteria are present in lagoons, more research needs to be undertaken in this area.

PHOTOGRAPH 12 – HEAVILY-LOADED ANAEROBIC LAGOON

PHOTOGRAPH 13 – PIGGERY LAGOON WITH PURPLE-SULPHUR BACTERIA

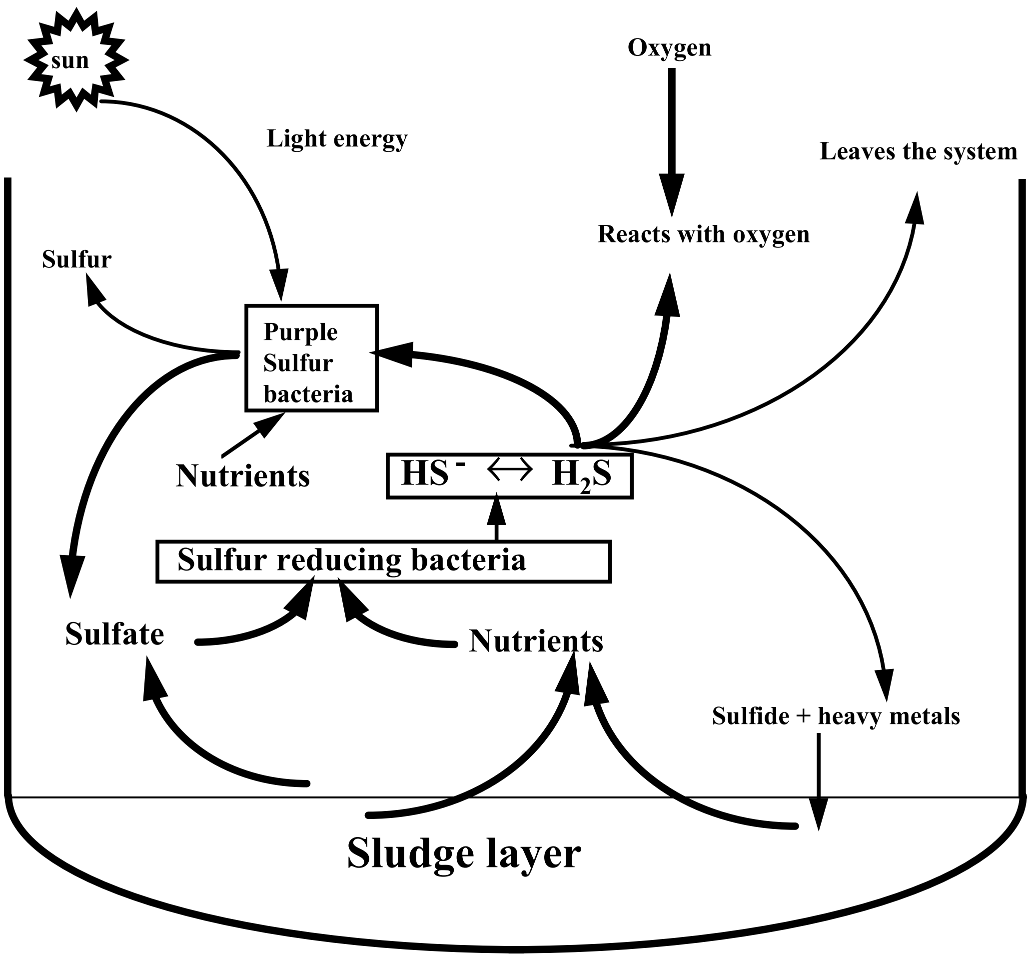


FIGURE 9 – SCHEMATIC REPRESENTATION OF THE MAJOR SULPHUR CYCLE IN AN ANAEROBIC ENVIRONMENT

(taken from Gebriel *et al.* 1999)

6.6.6 Ozone Treatment

According to the Board of Governors, University of Carolina (1998), "ozone is a gas that reacts chemically with many compounds and is an oxidising agent frequently used in effluent treatment application for odour control. Ozone high in the atmosphere shields the earth from solar radiation. At ground level, however, the gas can be toxic. Ozone has been used as a disinfectant and deodorising agent. Several laboratory and field evaluations of ozone treatments have been conducted or are ongoing. Belgian researchers obtained slightly improved daily growth and feed efficiency of finishing pigs as well as noticeable odour reduction by ozonating air in a finishing building. Researchers at Michigan State University reduced odorous compounds and disease-causing bacteria by treating piggery manure slurry with high concentrations of ozone.

Due to the toxic nature of ozone, there is opposition to using ozone to treat indoor air spaces. Several professional groups including Occupational Safety and Health Administration and the American Lung Association have expressed concern that the levels of ozone required to effectively deodorise polluted indoor air often exceed

recommended or permissible exposure limits for humans. There do not appear to be major objections to ozonating treatment lagoon water from a human health standpoint, but health concerns with indoor ozone are likely to cause health and safety regulators to address lagoon ozonation as well. Nevertheless, the relatively high indoor odorant levels in some livestock buildings and the potential for ozone to be rapidly depleted, thus minimising ozone emissions to outdoor air, continue to make ozonation of indoor air an attractive but controversial possibility. Some vendors have expressed keen interest in developing and marketing ozonation systems.

There are several ozone systems on the market, and some are being tested on livestock farms. One study involves a system in which ozone is generated inside specialised boxes, pulled into a swine building and distributed into the indoor air, and also pulled into a device floating on a lagoon and injected into the lagoon water in small bubbles. Odour reduction has been noticed in buildings and from lagoons when this system was in use. Since ozonated lagoon water can be recirculated into the building manure pits, this method can also reduce indoor odours by reducing odorous gases produced in the manure pits. However, long-term effects on lagoon treatment and sludge build-up have not been evaluated.

One particular ozone system for a swine finishing farm is projected to cost about $10,000 per building ($11 per pig space) for the ozone generating equipment and fans and tubes to distribute air in the building, and $50,000 to $60,000 for ozonating equipment for a large lagoon (roughly $6 to $7 per pig space for 10 buildings served by the lagoon). The electrical costs are likely to be the largest operating cost. The ozone generating cabinets draw roughly 700 watts, which, with four cabinets per building, could cost $1,000 or more per year ($1.14 per pig space per year), depending on electricity costs and operating time. The lagoon ozonator power levels are on the order of 10 kilowatts, which could handle up to 10 finishing buildings, which could then cost $6,000 or more per year for continuous operation, or $0.68 per pig space per year for 10 buildings. Since this technology has not been thoroughly tested, the costs may come down as ozonating requirements become better known. However, more testing is needed before ozonation of lagoons or air inside piggery facilities can be recommended".

Williams and Schiffman (1996) studied the use of an ozone generator to introduce ozone to a piggery shed at a concentration of 0.8 ppm (as determined by Drager tube analysis). Air samples were collected within the shed and from the exhaust fans at the treated facility and an adjacent facility receiving no treatment. The number and ages of the animals within each facility were approximately the same. Evaluation of odour levels by a panel, showed no detectable difference between the ozone-treated and non-treated sheds.

Wu *et al*. (1999) constructed a pilot-scale ozonation system to reduce odours from fresh and stored piggery manure slurry. Ozonation eliminated odorous bacterial metabolites from the manure slurry. The odour intensity of the manure slurry was also significantly reduced. The ozonated manure did not regain its original malodour after one month of storage subsequent to ozonation.

6.7 Odour Entrapment

6.7.1 Odour Entrapment Concepts

Odour entrapment involves fully enclosing the odour-producing source such that the odorous air is vented through a single point where treatment can occur. This could involve converting a piggery shed from natural ventilation (where fugitive emissions are uncontrolled) to a mechanically-ventilated design where all ventilation air can be ducted to a specific site (e.g. high stack, biofilter). Similarly, an air-tight cover could be fitted to a lagoon and the emitted gases (methane plus odorous compounds) treated or removed. Treatment could be by flaring, biogas utilisation or biofilter treatment.

6.7.2 Impermeable Lagoon Covering

The use of impermeable covers to fully trap gases emitted from effluent treatment lagoons was first investigated during the energy crisis of the 1970's. Air-tight covers are placed over anaerobic lagoons for two reasons.

Firstly, the cover can be used for odour control. All gases generated by the anaerobic processes in the lagoon can be captured and then flared off. There are a number of these types of lagoon covers installed in Australia, mainly at abattoirs and food processing factories.

Secondly, biogas can be collected and used as an energy source. The methane concentration in lagoon biogas is typically 60% to 65%. Biogas production is controlled by VS loading rate and lagoon temperature. Biogas production drops appreciably when lagoon temperatures drop below 15°C. (Safley and Westerman, 1989). Anaerobic lagoons are not as efficient as process-controlled digesters but are low cost and require little maintenance. We are not aware of any covered anaerobic lagoons in Australia where methane is used as an energy source.

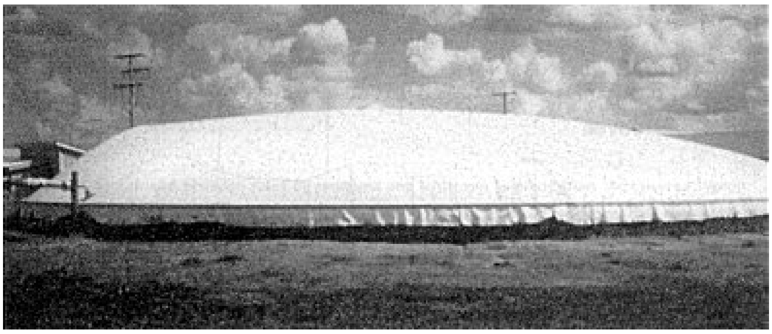
Examples of this work are Safley and Westerman (1988), Safley and Westerman (1989) and Sharpe and Harper (1999). Williams *et al*. (1998) describe the design, construction and anticipated operation of a lagoon-type methane (biogas) recovery system for the Cal Poly Dairy housing approximately 350 cows, heifers and calves. The lagoon was designed and constructed according to USDA-NRCS standards. It will be covered with a flexible membrane for collecting biogas to fuel a micro-turbine electric generator, and to produce up to 25 kW in parallel with the utility system. Odour control is the most important non-economic benefit. In addition, electrical and hot water benefits from the biogas combustion will be $16,000 per annum. Moser *et al*. (1998) has costed examples of biogas (methane) digesters on piggeries as alternatives to conventional lagoon systems. Included in their analysis are covered lagoons. Mannebeck (1985) shows some impermeable covers that have been used on liquid manure tanks in Europe.

Zhang and Gaakeer (1996), Zhang and Gaakeer (1998), Saskatchewan Agriculture and Food (1997) and Prairie Swine Centre Inc. (1998b) describe the construction of a low-cost, balloon-type lagoon cover for a 200-sow piggery in Saskatoon, Canada (see Photograph 14). The covering is a 0.91 mm thick hypalon roof-covering tarp that seals a lagoon air-tight. The dome-shaped cover, 2.5 metres high and 23 metres in diameter, is tightly secured to the concrete tank's sides with rubber stripping and bolts. Besides confining odours and gases, the cover prevents

precipitation from entering the tank. The tarp is then inflated and maintained at a constant pressure using a low-pressure air pump (100 Pa).

The structure can be viewed at http://www.aginfonet.com/agricarta/content/prairie_swine_centre/vol5num1_covering.html. The authors report that very little odour or ammonia escapes. However, there is no discussion about methane generation from the lagoon and its safe release to the atmosphere. The only conclusion is that temperatures are so low that little organic breakdown occurs. This is not applicable to Australian conditions.

We are not aware of any piggery in Australia that has an impermeable lagoon cover that collects biogas. The only piggery that collects methane is Berrybank Farm at Windermere near Ballarat (see Section 7.10) but this piggery uses an anaerobic digester. There is a covered anaerobic lagoon treating yeast by-products at Gatton College, Queensland. There was a covered and flared treatment lagoon at an abattoir at Aberdeen, NSW but this abattoir has been closed down.



PHOTOGRAPH 14 – INFLATABLE COVER OVER LAGOON

6.8 Odour Dispersion Enhancement

6.8.1 Dispersion Enhancement Concepts

The impact of odour releases on neighbours can be reduced by rapidly dispersing the odour. Options to aid dispersion include:

- Venting odorous air through a high stack
- Prevention of odour emission during poor dispersion conditions
- Increased turbulence at the emission source due to wind breaks, trees or rough topography.

6.8.2 Windbreak Walls

In Taiwan, more than 200 poultry farms have erected windbreak walls downwind of the fans that exhaust air from tunnel-ventilated poultry buildings to limit dust and odour emissions from the buildings. These structures provide some blockage of the fan airflow in the horizontal direction. The walls work by reducing the forward momentum of airflow from the fans, which is beneficial during low-wind conditions, as odorous dust settles out of the airflow and remains on the farm. Recent research indicates that windbreak walls also deflect fan airflow so that air flows higher above

the ground or the surface of downwind lagoons. A modelling study predicted that tall wind barriers placed around a lagoon would reduce odour emissions from the lagoon. Although the operating cost of windbreak walls is relatively low, periodic cleaning of odorous dust from the walls is necessary for sustained odour control, unless rainfall is sufficient to clean the walls. Installation of windbreak walls is estimated to cost at least $1.50 per pig space (e.g. $1,500 for a building that houses 1,000 pigs) (Board of Governors, University of Carolina 1998).

Research to evaluate windbreak walls for dust and odour control is continuing in North Carolina and Taiwan. It is difficult to determine the effectiveness of windbreak walls due to several factors. As wind speed and direction shift, the airflow from building fans changes direction. As a result, it is difficult to measure odour downwind. Also, odours emitted from the lagoons complicate the situation. Several researchers believe that measurement of the impact of windbreak walls on airflow and the dust and odour levels in the airflow at the wall location should be incorporated into dispersion models to predict the downwind impacts of those emissions.

Windbreak walls would not be suited for animal buildings equipped with multiple fans at non-uniform locations around the building. However, special dust-break devices have been designed for these situations and are being tested in Iowa. These devices employ a vertical plate to capture and settle dust particles. Experiments are being conducted with these vertical plates to see if they can be chemically treated to reduce odorous compounds.

The success of windbreak walls in Taiwan, anecdotal accounts of windbreaks alleviating neighbour's concerns in the U.S., the relatively low operating cost of windbreak walls, and results of the North Carolina windbreak wall study are expected to stimulate further experimentation with airflow deflection devices such as windbreak walls downwind of animal buildings.

These solutions are likely to have little practical application in Australia as the system relies on having mechanically-ventilated sheds.

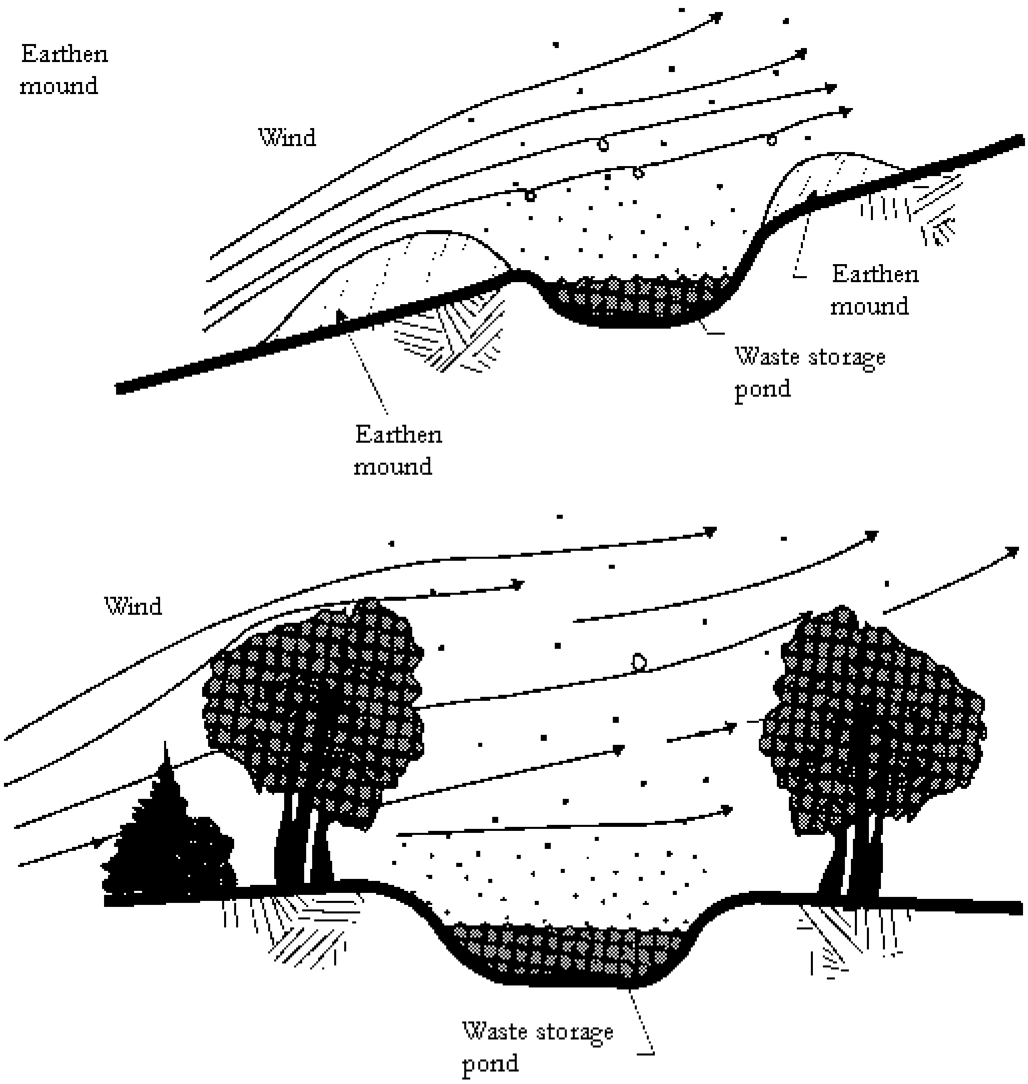
6.8.3 Tree Barriers

Odours disperse more rapidly if the surface over which the odours are moving is aerodynamically rough. Surface roughness causes enhanced turbulence and more dispersion of odours. Surface roughness is measured by the parameter, z_0 (roughness length) and is an input to odour modelling. However, in odour modelling terms, surface roughness is the average roughness between source and receptor. It is not a single belt of trees surrounding a piggery.

A single belt of trees around a piggery should have an effect on dispersing odours at the source. This is shown in Figure 10. According to the Board of Governors, University of Carolina (1998), "rows of trees and other vegetation known as shelter belts, which have historically been used for snow control in colder climates, may have value as odour control devices and to create a visual barrier. A properly designed and placed shelterbelt could conceivably provide a very large filtration surface for both dust and odorous compound removal from building exhaust air. However, it may take several years to grow an effective vegetative windbreak. Studies indicate that trees in shelter belts can absorb odorous compounds, and they create turbulence that enhances odour dispersion upward, particularly under stable

night time conditions. This action accelerates the dilution of odorants. Shelter belts should be inexpensive, especially if the cost is figured over the life of the shelter belt. There is concern, however, that the roots of trees in a shelter belt could disrupt the impervious layer of an anaerobic lagoon, causing the lagoon to leak". This is a site-specific issue and would not apply in many circumstances.

The true effectiveness of single-belt tree barriers has yet to be proven.



Source: NRCS Agricultural Waste Management Field Handbook

FIGURE 10 – CONCEPTUAL DIAGRAM OF THE EFFECT OF SHELTER BELTS

6.9 Summary – Odour Reduction Strategies

The following conclusions have been drawn regarding odour reduction strategies for Australian piggeries.

- Diet modification may have a role for existing piggeries with a substantial odour problem but there is insufficient data to use diet modification as an odour reduction strategy for a new or expanding piggery.

- There is a wide range of odour control additives. As with diet modification, they may have a role for existing piggeries with a substantial odour problem. However, the scientific validity of their effectiveness is inconclusive.

- Oligolysis or ozone treatment are of academic interest only and have not been shown to have practical applications.

- Dry handling of manure has good potential for significant odour reduction. Dry handling reduces or eliminates the need for the treatment lagoons that are the main source of odour. Deep-litter systems have proven odour reduction potential problems. Dry handling of manure in conventional piggery sheds also has potential but the practicalities of such a system need resolving.

- Biofilters are a proven method of odour treatment. While they have been shown to operate well in piggeries in Europe and North America, their applicability in Australia is limited as few sheds are mechanically ventilated.

- Biofilters for lagoons (permeable, organic covers) have good potential for odour control at Australian piggeries. Experience in Canada suggests that lagoons covered with straw should emit little odour. However, the practical issues of maintaining an intact straw cover throughout the year need to be addressed. Covering lagoons with a floating organic material (such as fat from an abattoir) should be examined.

- Impermeable covers (that collect methane and odorous gases) have potential for odour reduction. The collected gas can be flared or use to generate power. However, as an odour control method only, the cost of durable, permanent lagoon covers may limit their use.

- Surface aeration of lagoons, theoretically, offers good potential for significant odour control. In Australia, this concept was promoted as “stratified lagoons” in the 1980’s but the system was not widely adopted. As with straw covers, practical issues need to be resolved.

- Considerable anecdotal evidence suggests that the presence of purple sulphur bacteria in a treatment lagoon means low odour emission. However, the circumstances favouring the growth of purple sulphur bacteria are not known. Lagoon design and management to promote these bacteria should result in odour control. However, the conditions that promote the growth of these bacteria are yet to be established.

- The effectiveness of tree barriers and other physical devices on odour dispersion are not clear.

7 PIGGERY EFFLUENT TREATMENT SYSTEMS

Using the components given in Figure 1, various effluent treatment systems can be designed. The following sections describe and analyse a range of alternatives. They are designed for a 200-sow (2010 SPU) and a 2000-sow (20100 SPU) unit. Piggery herd numbers and manure production are given in Appendix A. The effluent treatment systems outlined include:

- Conventional systems common in Australia
- Innovative systems from Australia and overseas
- Systems proposed by Watts (1999b) specifically to reduce odour.

Note: Farran *et al*. (1997) reviewed a number of piggery effluent treatment systems as part of a methane emissions study. Their work is used extensively below. However, limited details are provided in their report. Because many of the underlying assumptions in the Farran *et al*. (1997) report are not stated, there are some minor differences between their data and that which is reported below. To provide consistency in the comparison of capital and operating costs, the Farran data has been used as a base and variations to suit particular options have been made.

7.1 Piggery Effluent Treatment in Australia

Safley *et al*. (1992) provides data on the various piggery effluent treatment systems used around the world (see Table 3). The preferred piggery effluent treatment system in Australia is clearly the anaerobic lagoon (55%) although this is not the global choice (5%). Dry storage and dry lot systems predominate in hot, dry third-world areas such as Africa and the Middle East. These systems (in the form of deep-litter sheds) are gaining in popularity in Australia. Liquid systems involve the collection of manure and spreading of manure as a slurry (without further treatment). These systems are suited to areas with cold winters that do not suit anaerobic lagoons or year-round effluent irrigation. Hence, these systems predominate in northern USA and Canada, and in Europe. Kruger *et al*. (1995) provides data on the types of effluent treatment systems used at piggeries in Australia (see Table 4). Their data also shows the dominance of anaerobic pond systems.

The selection of a particular effluent treatment system should consider:

- Local climate
- Environmental constraints
- Final utilisation site of nutrients
- Capital costs
- Operating costs
- Labour requirements
- Convenience
- Technical requirements

In Australia, the chosen system is usually low capital cost, low operating cost, low labour input and is not constrained by cold climates. Historically, the environmental constraints of very close neighbours and limited land for nutrient spreading have often not applied. Hence, the most common systems used in Australia are treatment by anaerobic lagoons and direct application of manure slurries to land.

TABLE 3 – GLOBAL PIGGERY EFFLUENT TREATMENT SYSTEMS (% BY REGION)

(from Safley *et al.* (1992))

Region	Anaerobic Lagoons	Liquid Systems	Daily Spread	Dry Storage and Dry Lot	Other Systems
Asia	1	38	1	53	0
Eastern Europe	8	39	0	52	1
Western Europe	0	77	0	23	6
North America	25	50	0	18	6
Latin America	0	8	2	51	40
Africa	0	7	0	93	0
Oceania	55	0	0	0	28
Near East and Mediterranean	0	32	0	68	0
Global Average	5	42	1	45	5

TABLE 4 – EFFLUENT MANAGEMENT PRACTICES IN AUSTRALIA

(taken from Kruger *et al*. 1995)

Treatment or Disposal Method	% Farms	% Sows
Solids separated from effluent	31	74
If solids are separated		
- land applied	21	49
- composted	6	32
- used for vermiculture	3	2
- other	4	6
Raw effluent (solids + liquid) disposed of without treatment	37	27
Effluent treated before reuse	59	84
If effluent is treated before reuse		
- anaerobic pond only	22	4
- anaerobic pond plus second stage pond	35	78
- other (eg methane digestion)	6	2
Raw or treated effluent disposed of by		
- tanker spreading	24	12
- spray irrigation	24	46
- pumped or piped onto land (not irrigated)	35	66
- evaporation / leaching	4	4
- disposal unknown	21	9

7.2 Summary of Treatment Options

Fourteen different treatment system configurations were analysed. The following is a brief summary of each option.

- Option 1 –Direct Land Application – Slurry Tanker

Wastes are flushed from conventional piggery sheds into a collection sump. The Manure slurry is pumped into a tanker and directly spread on agricultural land without treatment.

- Option 2 – Direct Land Application – Irrigation and Composting

Wastes are flushed from conventional piggery sheds into a collection sump via a rundown screen (solid separator). A rundown screen only removes about 25% of volatile solids. The solids are composted with a bulking agent (sawdust, straw) and sold off-site as fertiliser. The liquid component is irrigated daily and without treatment onto agricultural land.

- Option 3 – Anaerobic Lagoon – No separation or recycling

Wastes are flushed from conventional piggery sheds into a conventional anaerobic pond (loading rate – 80 $gVS/m^3/day$). This pond overflows into a secondary (holding) pond from which effluent is irrigated onto agricultural land. Irrigation can be timed to match crop and weather conditions. Once in every ten years (or so), sludge is removed from the anaerobic pond, composted and sold off-site as fertiliser.

- Option 4 – Anaerobic Lagoon – Solid Separation

This option is the same as Option 3 except that solids are separated from the waste stream using a rundown screen prior to entry to the anaerobic pond. This reduces the required capacity of the anaerobic pond. Solids are composted and effluent is irrigated.

- Option 5 – Anaerobic Lagoon – Solid Separation and Recycling

This option is the same as Option 4 except that treated effluent is recycled from the secondary pond back through the piggery as flushing water. This reduces the requirement for clean water at the piggery, reduces the irrigation requirements and allows more frequent flushing (and thus cleaner sheds).

- Option 6 – Mechanically-aerated Lagoon

Wastes are flushed from conventional sheds into a mechanically-aerated basin. No solids are removed. After treatment, the effluent flows into a storage lagoon prior to irrigation. Treated effluent is recycled as flushing water. Accumulated sludge is removed, composted and sold off-site. Mechanically-aerated treatment ponds are typical of sewage and food processing waste treatment systems. They are reliant on good management and maintenance. Problems rapidly develop if the aerators break down.

- Option 7 – Covered Anaerobic Pond

This option is similar to Option 5 except that the anaerobic pond has an impermeable cover. Methane and odorous gases are collected under this cover. This biogas can be used as an energy source or simply flared (burned) off. The pond cover significantly reduces odour emissions but adds extra capital cost. The pond loading rate is increased so that pond size can be decreased thus reducing capital cost.

- Option 8 – Anaerobic Digester

In this option, wastes from the piggery are anaerobically digested in a controlled system using digester tanks. Biogas is produced and this generates electricity for sale to the local grid. This system is expensive and complex but eliminates odour and has the potential to generate income from sales of electricity and fertiliser.

- Option 9 – Complete Deep-litter system

In this option, conventional piggery sheds are replaced with deep-litter sheds. These sheds (known as ecoshelters) are low cost, greenhouse-type sheds in which a deep layer of litter (sawdust, straw, rice hulls) is placed. The pigs manure mixes with the litter and composts. At the end of each batch, the manure plus litter is removed and sold off-site as compost. No ponds are required. Provided that the litter remains aerobic, this is a very low odour option. However, there are pig health and growth performance issues that make this system undesirable for a full farrow-to-finish piggery.

- Option 10 – Combined Anaerobic Lagoon / Deep-litter System

This option is a combination of Option 5 (for the breeding section of the piggery) and Option 9 (for the grow-out section of the piggery). The breeding herd is housed in conventional sheds and wastes are flushed into an anaerobic pond. AS the breeding herd produces about one third of the total manure at a piggery, the size of the anaerobic ponds is much smaller than a conventional system.

- Option 11 – Surface-aerated Ponds

This option is the same as Option 5 except that the anaerobic pond is mechanically surface aerated. Research indicates that this should significantly reduce odour emissions but adds capital and operating costs.

- Option 12 – High efficiency Solid Separation

This option is the same as Option 5 except that the rundown screen is replaced with a high-performance centrifuge solid separator. About 65% of volatile solids are removed from the waste stream. Hence, the size of the anaerobic pond is reduced. However, this adds significant capital and operating costs.

- Option 13 – Anaerobic Lagoon plus Evaporation Pond

In this option, wastes are flushed into an anaerobic pond (without solid separation). Treated effluent overflows from the anaerobic pond into an evaporation pond. There is no effluent irrigation and no composting of screened solids. Occasionally sludge is removed. The size of the evaporation pond is dependent on the local climate but a large surface area is needed. A large surface area means a large odour-emitting surface. This system has very little daily operational requirements and is therefore attractive to pig producers.

- Option 14 – Integrated Floc-based Sequence Batch Reactor

This is an experimental system being tested at a NSW piggery. Wastes are treated in a digester tank that is periodically aerated and non-aerated. This sequencing of each

batch of effluent results in BOD and nitrogen removal. This is a technically complex system.

7.3 Option 1 - Direct Land Application – Slurry Tanker

This is the simplest effluent “treatment” method possible. Pigs are housed in conventional sheds with under-floor flushing channels. Effluent is flushed into a sump (below-ground concrete tank). The collected effluent is then pumped into a slurry tanker and spread directly (without treatment) to land. This is shown schematically in Figure 11.

Farran *et al*. (1997) estimated that a 70,000 L sump was required for the 200-sow unit and a 200,000 L sump for the 2000-sow unit. They estimated that the 200-sow unit required 110 ha of land and the 2000-sow unit required 1000 ha. Our analysis agrees with these land areas, with phosphorus loading being the limiting factor. The 200-sow unit required a tractor plus 14,000 L tanker to spread the effluent. The 2000-sow unit required three tractors and tankers.

With a flushing volume of 20 L/pig/d and a hosing volume of 2 L/pig/d and no recycling of water, the 200-sow unit requires 23 ML/yr of clean water. The 2000-sow unit requires 232 ML/yr. (Note: A flushing volume of 20 L/pig/day has been used for consistency in the following options. In reality, for options that do not recycle effluent, this is a high flushing volume and total water use is probably over-estimated.)

The advantages of this system are simplicity and maximisation of the use of nutrients as fertiliser replacements. Organic matter additions to soils are also maximised. The disadvantages of this system are that manure must be spread virtually every day of the year, regardless of weather conditions. Applications are not determined by crop water demand. This makes this system unsuitable for an area with a wet climate as there is a high risk of runoff of spread manure. If the effluent is not spread regularly, the effluent accumulating in the sump can rapidly become anaerobic, resulting in the emission of strong odours. Similarly, spreading of the effluent can cause strong odours to be emitted. Odours emitting during spreading can be minimised if direct-injection into the soil is used rather than surface spreading. This system also relies on there being sufficient land available close by to sustainably spread the effluent.

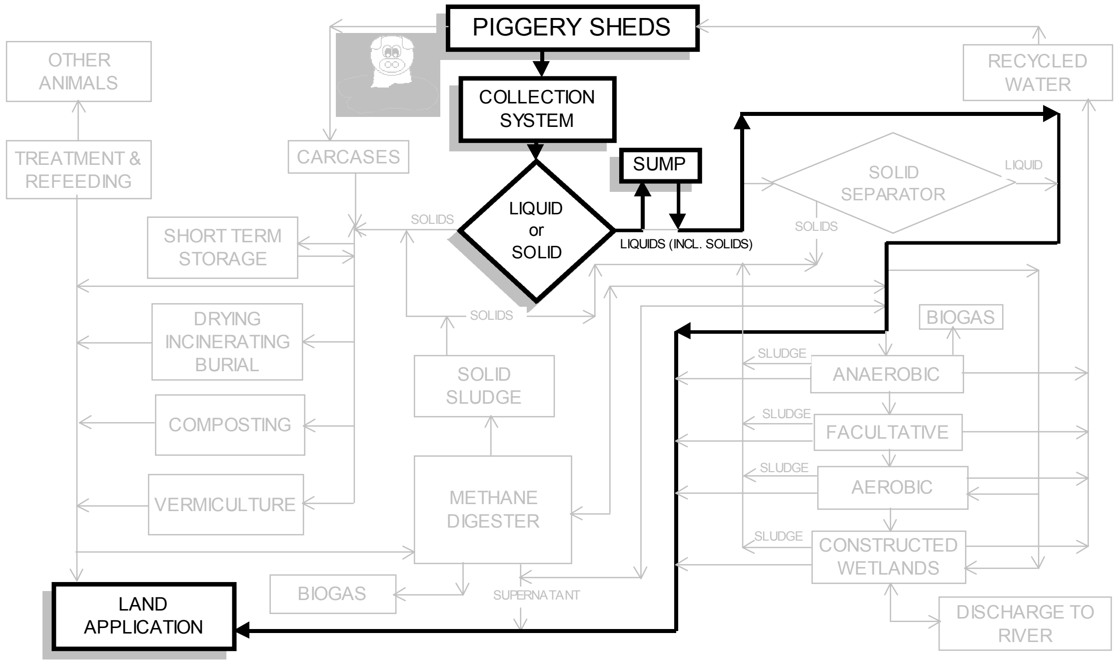


FIGURE 11 – OPTION 1 – DIRECT APPLICATION – SLURRY TANKER

7.4 Option 2 - Direct Land Application – Irrigation and Composting

This option is similar to Option 1 except that the effluent from the shed goes through a solids separator. This removes gross solid and the remaining effluent can then be irrigated rather than being spread by machine (see Figure 12). The solids can be composted and sold off-site. This reduces the land area required on-site but only in proportion to the phosphorus removal rate of the screen. Effluent can be irrigated with a travelling irrigator but odours can be an issue. There is an increased labour requirement with this system. As there are no treatment lagoons, irrigation must occur virtually every day and this is not necessarily environmentally acceptable.

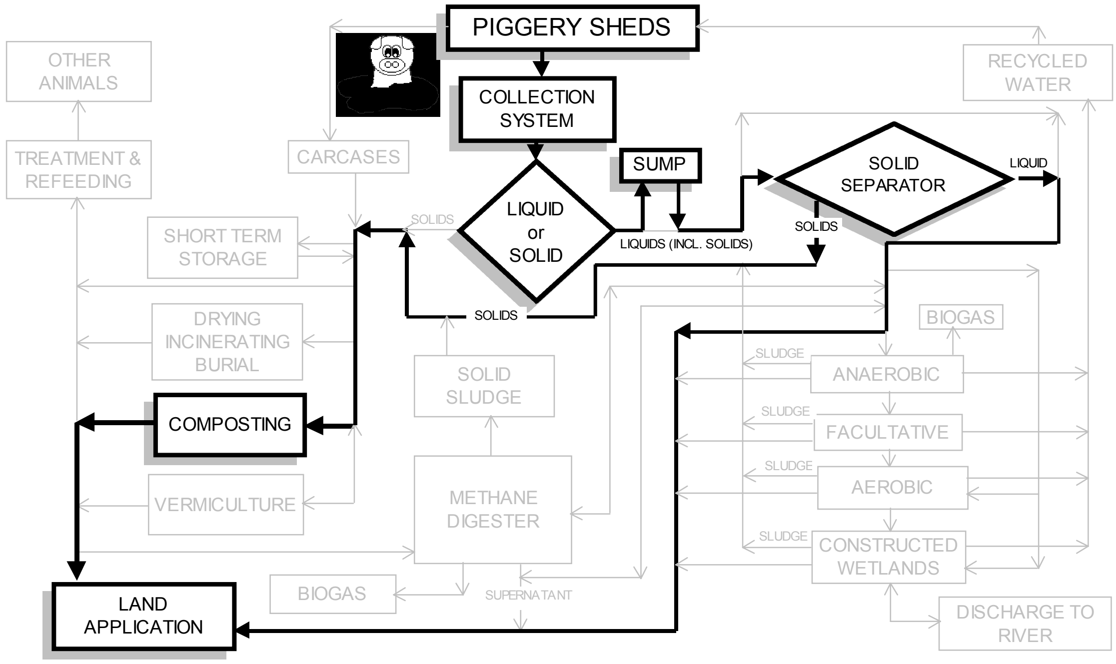


FIGURE 12 - OPTION 2 - DIRECT LAND APPLICATION – IRRIGATION AND COMPOSTING

7.5 Option 3 - Anaerobic Lagoons – No separation or recycling

In this system, effluent is flushed directly from the piggery sheds into an anaerobic lagoon. Organic matter is broken down in that lagoon. This lagoon overflows to a secondary (facultative / wet-weather / holding) lagoon from which irrigation is drawn. There is no separation of solids prior to treatment and no recycling of treated effluent. Solids simply accumulate in the bed of the anaerobic lagoon. Once in every 10 years (or so), the lagoon is desludged. The sludge is then spread on agricultural land or removed from the site. This system is shown in Figure 13.

Typically, the anaerobic lagoon is designed for a volatile solids loading rate of about 80 g VS /m^3/day (see Section 5.3). Provision for ten years of sludge accumulation is made. Hence, the total volume of the lagoon consists of an active volume plus a sludge volume. The sludge volume is often 25-40% of the whole lagoon. This usually means that the lagoon capacity is 4 – 8 m^3 per pig.

The advantage of this system is that there is no need to handle solids (except when desludging) and irrigation does not need to occur every day. Depending on the size of the secondary lagoon, irrigation can be timed to match soil and crop requirements. As sludge can be taken off-site, land requirements on-site are reduced.

In the Farran *et al*. (1997) analysis, the secondary lagoon had a capacity of 83 ML for the 2000-sow unit. This was a generic size based on the need to hold 6 months of inflow. For the Murray Bridge area, the low rainfall means that year-round irrigation is possible. MEDLI modelling was undertaken using Murray Bridge climate data and it was concluded that very infrequent lagoon overflows would occur with a secondary lagoon of 10 – 15 ML capacity.

The disadvantages of this system are odour potential from the lagoons and water use. As there is no recycling, all effluent entering the lagoon must be irrigated (or evaporated).

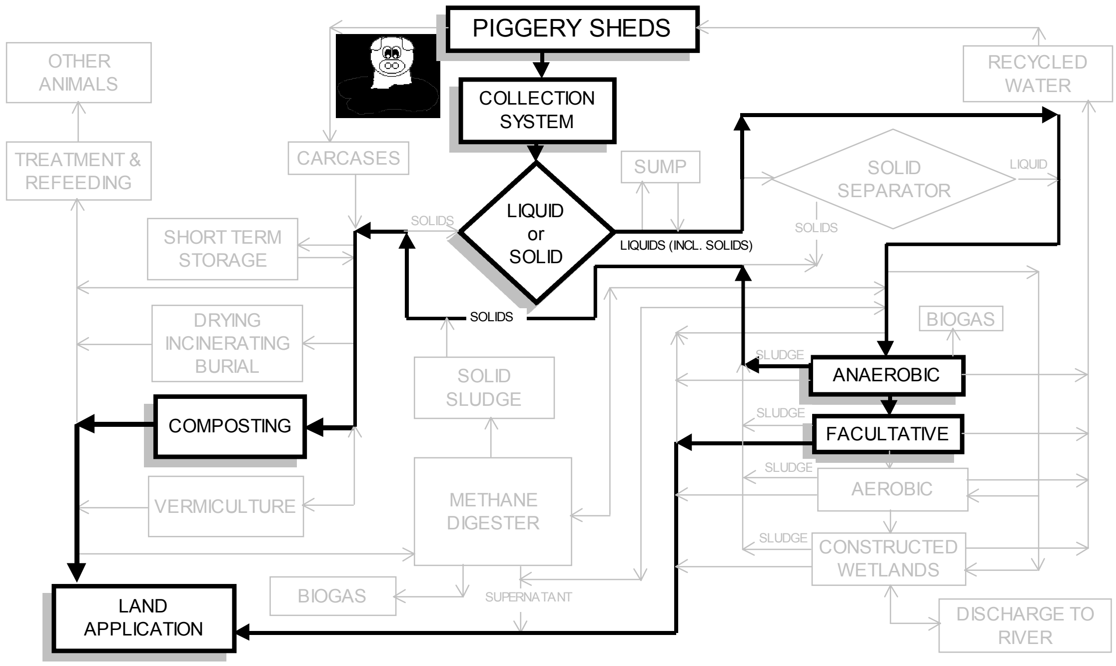


FIGURE 13 - OPTION 3 - ANAEROBIC LAGOONS – NO SEPARATION OR RECYCLING

7.6 Option 4 - Anaerobic Lagoons – Separation, no recycling

This option is identical to Option 3 except that solids are removed from the flushed effluent (see Figure 14). The advantage of this approach is that the treatment capacity of the anaerobic lagoon is reduced (and odour emission is reduced). The solid by-products must be handled in such a way that a secondary odour nuisance is not created. Composting is a good option.

7.7 Option 5 - Anaerobic Lagoons – Separation and recycling

This option is identical to Option 4 except that about 60% of the flushing water used in the piggery is recycled from the second lagoon. This greatly reduces the clean water requirement for the piggery and reduces the irrigation area needed.

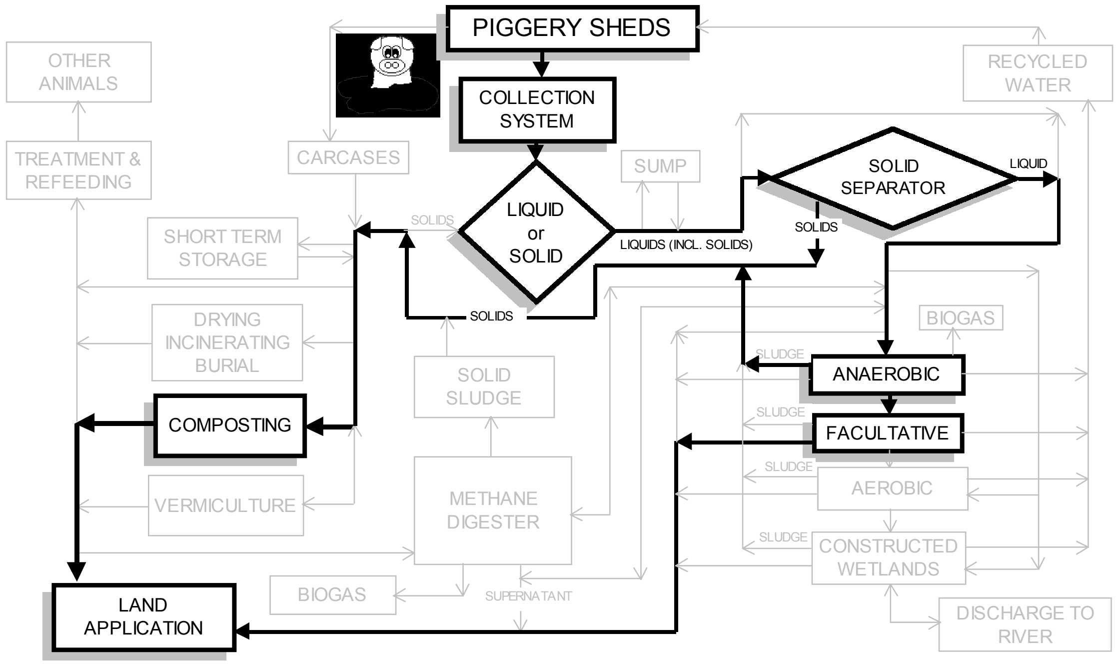


FIGURE 14 - OPTION 4 - ANAEROBIC LAGOONS – SEPARATION, NO RECYCLING

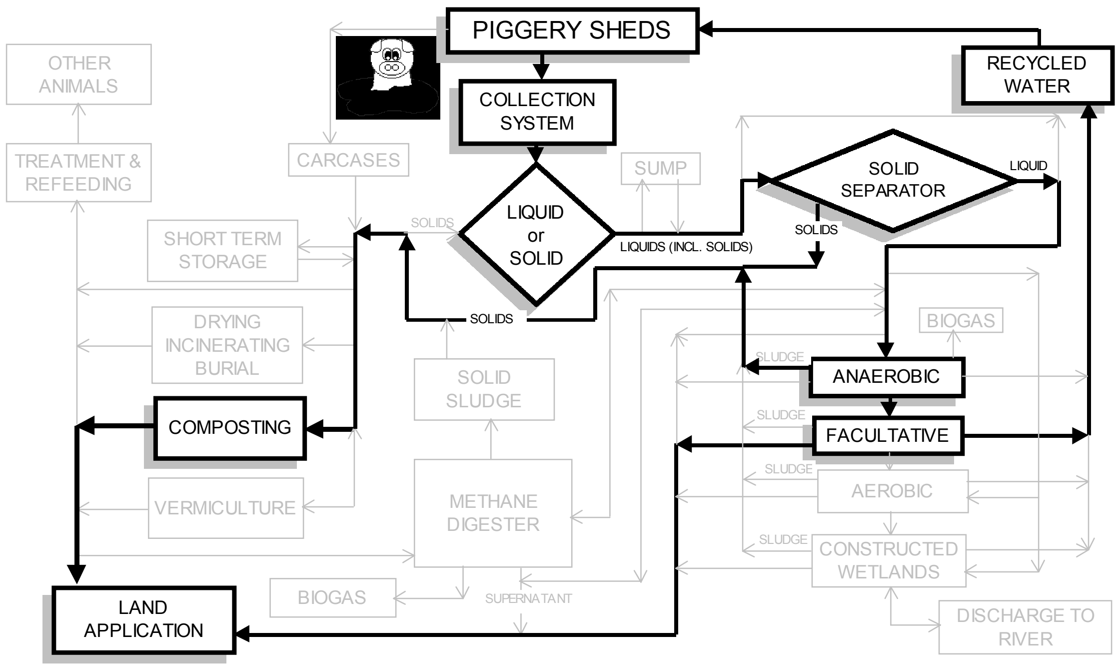


FIGURE 15 - OPTION 5 - ANAEROBIC LAGOONS – SEPARATION AND RECYCLING

7.8 Option 6 - Aerobic Treatment System

Aerobic treatment lagoons emit little odour when compared to anaerobic lagoon. For aerobic conditions to exist, there must be sufficient free oxygen in the lagoon, particularly in the surface layers. Natural aeration (caused by wind) is an inefficient process and very large surface areas are required to achieve sufficient aeration.

Hence, most truly aerobic treatment systems have mechanical aeration of the lagoon. Aeration of polishing lagoons is relatively common in sewage treatment systems but we are not aware of any fully mechanically-aerated piggery effluent treatment systems in Australia.

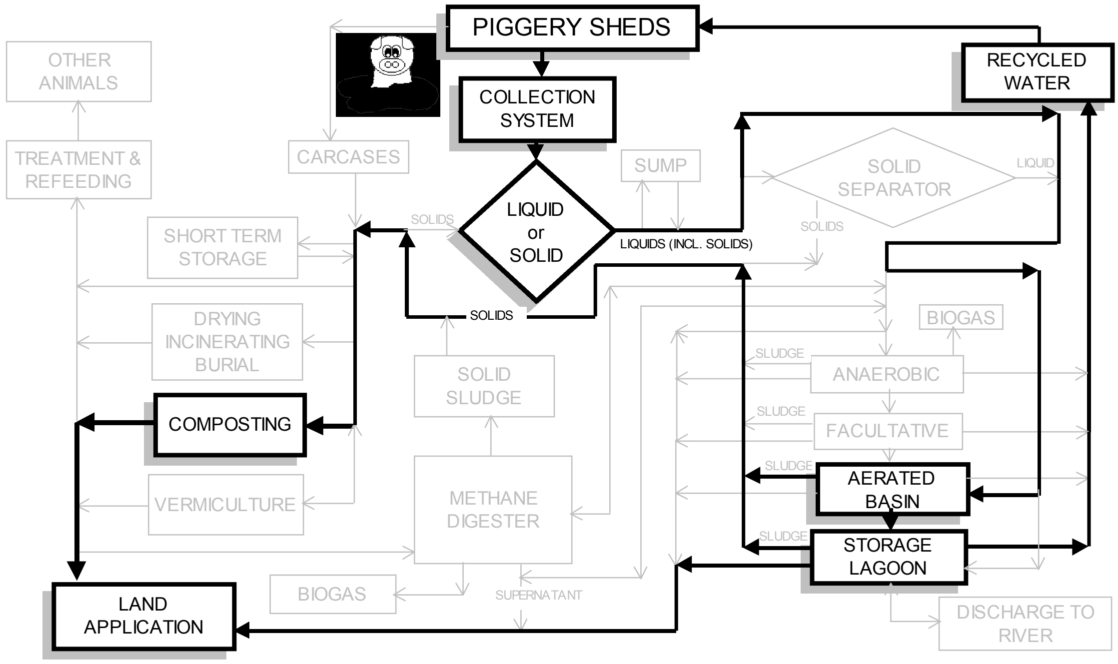


FIGURE 16 - OPTION 6 - AEROBIC TREATMENT SYSTEM

The analysis for this option is taken directly from Farran *et al*. (1997). Piggery effluent is flushed into a mechanically-agitated aeration basin (see Figure 16). After treatment, the effluent flows into a storage lagoon prior to irrigation. Flushing water is recycled from the storage lagoon. Sludge removed from the storage lagoon is recycled to the aeration basin for further treatment. The design criteria are taken from NZAEI (1985) and Kruger *et al*. (1995). The design parameters are:

Mixing power requirement	7.5 kW/1000 m^3
Aeration lagoon depth	> 3 m
Aeration efficiency	1.5 kg O_2/kW-hr
Oxygenation capacity	2 x BOD loading
Hydraulic retention time	10 days

System Specification	200-sow unit	2000-sow unit
Aeration basin (m^3)	600	6000
Mixing power (kW)	4.5	45
Aeration power (kW)	16.8	168
Clarifier (m^3)	50	400
Storage lagoon (6 mth)(m^3)	8300	83000

As with the anaerobic lagoon options, we have decreased the capacity of the storage lagoon to suit Murray Bridge conditions.

The advantages of this system are low odour emission (provided all of the equipment remains operating at optimum performance).

The disadvantages of the system are high capital and operating costs and continual maintenance. To achieve full aeration of a lagoon, the aerators require high input of energy (electricity).

PHOTOGRAPH 15 – SURFACE AERATOR ON TREATMENT LAGOON

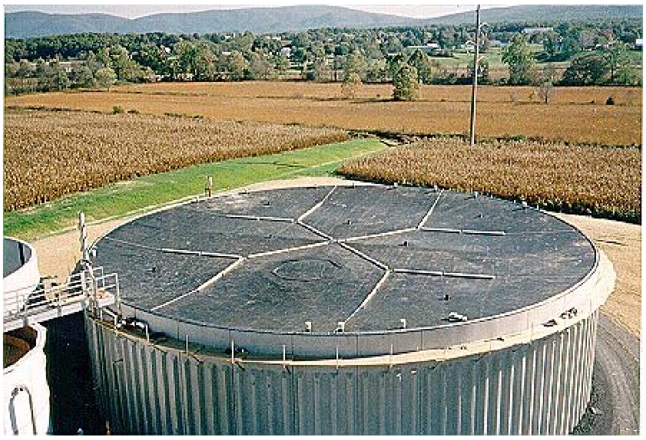
A variation of this method is to only aerate the surface layers of a conventional anaerobic treatment lagoon (see Section 6.6.4 and Photograph 15). In Australia, this is called a stratified lagoon and this system was adopted at some piggeries in the late 1980's. This system is analysed as Option 11.

7.9 Option 7 - Covered Anaerobic Lagoon

Photograph 14 shows a covered lagoon. These covers are discussed in Section 6.7.2). The system is shown schematically in Figure 17.

There are a number of issues to be addressed when designing a lagoon cover. There are several synthetic cover materials available. Each has a different strength, life and capital cost. A stormwater removal system is essential to prevent the cover from being torn or pulled out at the edges. The gas collecting under the cover contains explosive quantities of methane and potentially toxic levels of H_2S. Excess methane can be removed by flaring (burning) but the flare can be a considerable portion of the total installed cost.

In Australia, GTI Australia (03-9509 6166) seems to have the most experience in this area. The parent company, Geomembrane Technologies Inc. of Canada (www.adi.ca/gti) has over twenty years experience in anaerobic cover design. GTI have installed over 80 covers including those at Melbourne Water's Western Treatment Plant, Warrnambool Milk and Kraft Foods Leitchville.



PHOTOGRAPH 16 – GTI MANURE TANK COVER

(taken from www.adi.ca/gti)

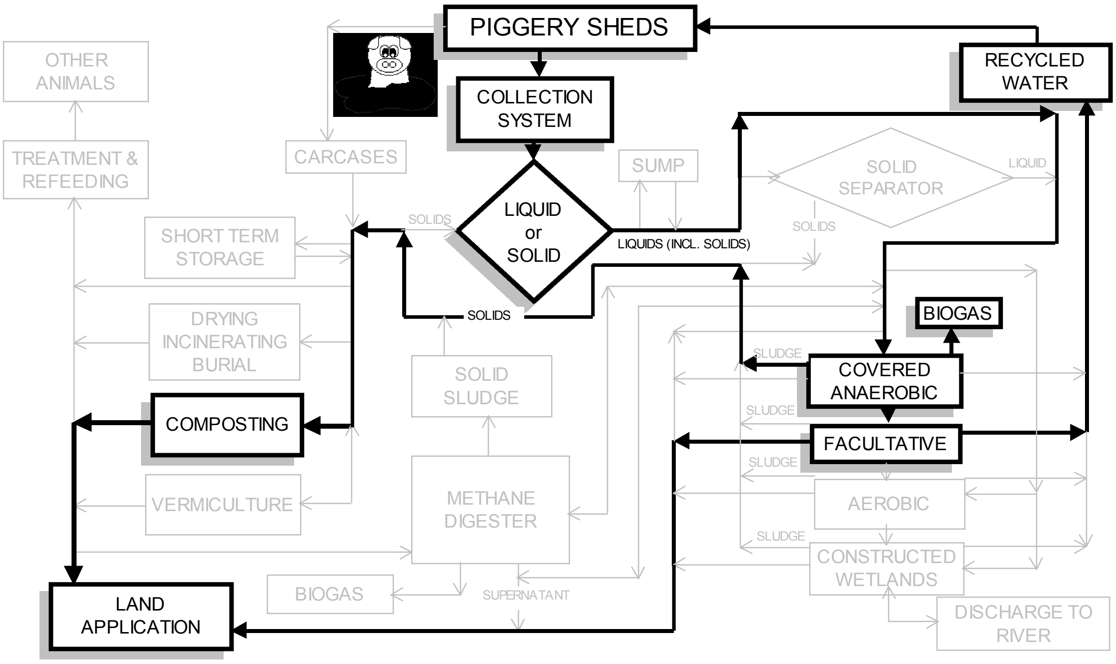


FIGURE 17 - OPTION 7 - COVERED ANAEROBIC LAGOON

The following analysis of a covered lagoon at a piggery is taken directly from Farran *et al*. (1997).

> Piggery effluent is flushed into a covered anaerobic lagoon. Biogas is drawn off from under the lagoon cover. The anaerobic lagoon overflows into a facultative lagoon. Flushing water is recycled from this lagoon and effluent is irrigated from this lagoon. Sludge is periodically removed from the anaerobic lagoon. This system is shown in Figure 17.

The initial design criteria for covered lagoons were derived from Safley (1990) and O'Shea (1995). These criteria are:

Hydraulic retention time	> 80 days
Volatile solids loading rate	193 g VS/m^3/day.
Biogas production	0.672 m^3/kg BOD removed (*)
Design used	0.343 m^3/kg BOD removed

* Farran *et al.* (1997) notes that further data from Safley and Westerman (1988 & 1989) give inflated values for anaerobic lagoon emissions with respect to what is theoretically possible.

System specifications	200-sow unit	2000-sow unit
Anaerobic lagoon (m^3)	4500	45000
Lagoon depth (m)	6	6
Area of cover (m)	40 x 40	55 x 55 (4 off)
Facultative lagoon (m^3)	8300	83000
Annual biogas production(m^3 x 10^6)	0.057	0.57

A similar analysis was undertaken for covered lagoons at Parkville Piggery near Scone, NSW (Wet Waste to Energy Study). This is an existing 15,500 SPU piggery where treatment lagoon remediation was required. The piggery has rundown screens and the solids are treated using vermiculture (see Section 5.12). There are currently two anaerobic lagoons. The options evaluated were:

- Covering one of the existing anaerobic lagoons
- Covering a new centralised anaerobic lagoon
- Installing an in-vessel digester for the screened solids.

Option 1 – Covering an Existing Anaerobic Lagoon

The existing lagoons have a surface area of 3,800 m^2 (35 m x 110 m) and an estimated depth of 1.5 m. The anaerobic lagoons have a capacity of 12 ML and a retention time of 40 days. The estimated loading rate is 120 gVS/m^3/day. The effluent would continue to be screened prior to entering the lagoon. High-density polyethylene (HDPE) was proposed as the covering medium as it is the cheapest material available and has been used elsewhere without serious problems. Nevertheless, the cost of the covering is $133,000. Other costs were $4000 for a condensate trap, $10,000 for a H_2S scrubber, $60,000 for a flare to burn excess gas, and other costs. The total capital cost was about $300,000. Assuming that the cogeneration saved $27,000 annually in electricity costs, it was concluded that the option could not be economically justified.

Option 2 – Covering a New Anaerobic Lagoon

In this option, the existing anaerobic lagoons are decommissioned and a new single, deep lagoon is installed. The smaller, deeper lagoon offers savings in lagoon covering costs. Solids would still be removed by screening. The lagoon would be 8 ML (40 m x 40 m x 5 m deep) with a loading rate of 400 gVS/m^3/day. The retention time would be 13 days. As with Option 1, sludge build up under the cover is an

issue. At present, there is no known system in Australia that allows for sludge removal without the cover being removed. The capital cost of this option was $497,420 but it was concluded that this offered a saving of $100,000 that was needed to upgrade the existing lagoons. Assuming that the cogeneration saved $32,000 annually in electricity costs, it was concluded that the option could not be economically justified.

- **Option 3 - Installing an in-vessel digester for the screened solids**

The digestion of the screened solids to produce biogas can be undertaken in a vessel digester. There are two examples of solids digesters being used for piggeries in Australia. The first is at Berrybank Farms Piggery near Ballarat (see Section 7.10) and consists of two steel tanks with a combined volume of 3400 kL (see Photograph 17). The second is a simpler system at the University of Adelaide, Roseworthy Campus piggery that is a fibreglass vessel with a volume of 60 kL. A similar system was proposed for Parkville. The digester would have a capacity of 0.1 ML and a retention time of 100 days. The loading rate would be 10,000 gVS/m^3/day. The capital cost would be $838,420. Assuming that the cogeneration saved $20,000 annually in electricity costs, it was concluded that the option could not be economically justified.

GTI Australia provided budget data on lagoon covering for piggeries.

In Option GTI1, three x 8000 pig grower units were to have a combined covered lagoon. GTI suggested a new anaerobic lagoon of a nominal 18 ML to 25 ML capacity complete with concrete walls, inherently safe trafficable cover, sludge removal system, biogas handling, automatic controls and flare (excluding earthworks and slurry transfer to the lagoon). The cost was estimated at $425,000 to $700,000 depending on site specific details. Electricity generation of up to 400 kW is potentially feasible and for an extra cost of about $480,000 could provide an income stream of $200,000 to $300,000 per annum depending on electricity price. This equates to a loading rate of 470 gVS/m^3/day for the 25 ML lagoon. We estimate that 3 x 8000 grower / finishers is about 27,000 SPU.

In Option GTI2, the piggery was a 10,000-sow unit (100,000 pigs). In this case, the lagoon capacity was 50 ML to 70 ML. The loading rate is as above. The estimated cost was $800,000 to $1,400,000 depending on conditions.

The capital costs of these schemes can be summarised as:

Farran *et al*. (1997)	200-sow unit	$ 90 / SPU
Farran *et al*. (1997)	2000-sow unit	$ 33 / SPU
Parkville Option 1	half of 15,500 SPU	$ 38 / SPU
Parkville Option 2	15,500 SPU	$ 32 / SPU
Parkville Option 3	15,500 SPU	$ 54 / SPU
GTI Option GTI1	27,000 SPU	$ 15 – 25 /SPU
GTI Option GTI2	100,000 SPU	$ 8 – 14 /SPU

However, care should be taken in comparing these costs. The Farran data is for a full effluent treatment system. The Parkville data is a remediation of an existing system. It does not include the cost of effluent irrigation and the solid screening – vermiculture system. The GTI data does not include irrigation, lagoon construction or manure conveyance.

Lagoon loading rates also vary. Typically, an uncovered lagoon would have a loading rate of about 80 gVS/m^3/day. Farran used a loading rate of 200 gVS/m^3/day while Parkville and GTI used a loading rate of 400 gVS/m^3/day. Clearly, the higher loading rate results in smaller lagoons and lower capital costs. While lagoons loaded at these rates would function, odour emissions would be greater. This is not an issue under the cover. However, outflow from the covered lagoons would be held in a holding lagoon prior to irrigation or evaporation. Due to incomplete treatment, odours could be emitted from the holding lagoon. There is insufficient experience with covered lagoons in Australia to be completely confident about their performance.

In all cases, the use of covered lagoons is not economically viable if assessed as a cogeneration plant. However, they have been installed as odour control devices. Presumably, in those cases, the high costs of lagoon covering and flaring were less than other odour control strategies or relocation of the whole facility.

The main advantage of lagoon covering is odour control. A well-designed system should virtually eliminate odour from the lagoons. Covering lagoons also allows for use or treatment of greenhouse gases, to reduce their emission rates.

The disadvantages of lagoon covering are high cost and on-going operating and labour costs.

7.10 Option 8 – Anaerobic Digestion

7.10.1 Berrybank

This option is based on the innovative system used at Berrybank Farms piggery near Windemere, Ballarat in Victoria.

Information about the Berrybank Farms system can be found at:
http://www.eidn.com.au/berrybank.html,
http://www.mov.vic.gov.au/FutureHarvest/case1.html, and
http://www.erin.gov.au/epg/environet/eecp/case_studies/berrybank.html .

Berrybank Farms piggery houses 15,000 pigs. It produces some 0.275 ML/d of effluent containing about 2% solids. In 1989, Berrybank Farms installed a sophisticated effluent management system to recover and treat all of the effluent to produce by-products suitable for use on the farm (as flush water, gas for electricity, and fertiliser), or for sale. The effluent management system is a seven-stage process including:

- automatic and continuous effluent collection
- grit removal
- slurry thickening
- primary digestion
- secondary digestion
- biogas purification and
- a cogeneration thermic plant.

PHOTOGRAPH 17 – BERRYBANK DIGESTERS

(taken from http://www.erin.gov.au/epg/environet/eecp/case_studies/berrybank.html).

Figure 18 shows a schematic of the treatment system. Effluent is automatically flushed from the sheds at various times of the day. Grit and large particles are removed from the slurry by sedimentation. The slurry is then pumped to the thickening plant, where the finer suspended solids are separated from the water. The clarified water is recycled, either as flush water in the piggery, put into storage, or applied directly to the land as fertiliser.

The thickening plant includes a screen and a flotation system. Flotation allows for the separation of water from the smaller suspended particles.

The primary and secondary digesters are where the anaerobic digestion takes place. The digesters provide the ideal conditions for anaerobic digestion to proceed at a faster, more controlled rate, by excluding air, thoroughly mixing the contents and maintaining optimum temperatures.

The biogas is then purged of potentially damaging sulphur by scrubbers, traps and a dehumidifier, before being pumped to the co-generation thermic plant, where it is converted into thermic heat and electricity. The plant currently produces 180 kW/hr of electricity for 16 hours per day (enough to power over 400 households), and has the potential to considerably boost this output. The farm's feed mill uses 60% of the electricity generated, and some of the electricity generated is used to operate the primary digester. Surplus electricity is sold to large power producers.

The solid and colloidal parts of the digested slurry are separated from the water using a centrifuge. This reduces the bulk of the slurry by up to 90%. The end result is composted humus. The separated water also contains residual nutrients. The system produces 100,000 L/d of recyclable water, 100,000 L/d of mineralised water and 7 t/d of solid by-products with a total solids content of 35%.

It is also claimed that the system has reduced water usage by 70%, improved stock and staff working conditions and eliminated odour.

The proponents of Berrybank present a cost comparison between a Berrybank-type system and a conventional anaerobic / aerobic treatment lagoon approach (see

). No details of the derivations of the costs given in this table are provided. Some costs (such as the saving of water at a back-calculated cost of $ 500/ML) seem very high. These figures also vary considerably with Farran *et al.* (1997) who estimated the cost of the system to be $ 1.8M (not $ 2.3M) compared to the cost of an anaerobic lagoon system at $ 0.4M (not $0.8M to $ 1.2M).

TABLE 5 – COST COMPARISON OF BERRYBANK AND CONVENTIONAL EFFLUENT TREATMENT SYSTEMS (20,000 PIG UNIT)

(taken from http://www.eidn.com.au/berrybank.html)

	Berrybank System (Consil Total Waste Management)	Anaerobic / aerobic lagoons
Capital Cost	$ 2,300,000	$ 800,000 - $ 1,200,000
Net Cost	$ 1,000,000 - $ 1,500,000	
Odour	Minimal	High
Water Use	250 m^3/day (91 ML/yr)	500 m^3/day (182 ML/yr)
Energy Recovery	70,000 MJ/day	Nil
Cost Saving – water	$ 45,000/yr (at $ 500/ML)	Nil
Cost Saving – energy	$ 156,000	Nil
Cost Saving – fertiliser	$ 300,000	Nil
Cost Saving – crop yields	$ 200,000	$ 200,000
Total Cost Saving	$ 701,000	$ 200,000
Net Cost Saving	$ 501,000	
Pay Back Time	3-4 years	
		Operating Costs
Generation of Electricity	$ 0.05 per kWHr	$ 5000/yr
Chemicals	$ 0.25 /L @ 1.7 % TS	$ 30,000/yr
Labour		$ 30,000/yr
Total Operational Costs		$ 65,000/yr

Agribiz Engineering (1999) estimated that the annual operating costs of a Berrybank-style operation for 2000-sows would be $250,000 and the potential income is approximately $650,000. The break-even size of a biogas digester is for a piggery with about 11,000 pigs, based on typical capital, operating and income costs. If odour reduction and other environmental factors are given a value, the economic size of the piggery will reduce accordingly.

7.10.2 Leitchville Study

Ecosound Solutions (1994) undertook a study to examine the feasibility of using the Berrybank treatment system for a group of piggeries near Leitchville in northern Victoria. A preliminary design for the system was prepared on the basis of waste treatment for eight piggeries, wastewater from the Kraft factory and sewage from the Leitchville and Gunbower townships.

It was proposed that waste be collected from individual sources and be conveyed to a central treatment facility to undergo anaerobic digestion under controlled conditions. The process would produce energy in the form of biogas as well as digested sludge with fertiliser and soil conditioning properties. The biogas and sludge

were available for sale. It was concluded that the inclusion of the sewage waste treatment was not operationally feasible and was more expensive than previous proposals. Wastewater produced at the central facility required further treatment in ponds prior to disposal and 506 ha of irrigation land was required. This wastewater treatment and disposal was the greatest cost burden.

The capital cost of the system was estimated to be $ 2.9 million. The most significant parameter was the optimisation of revenue from the sale of products developed from the digested sludge. The system was not economically viable based only on the revenue from the collection of waste, the sale of gas and/or the sale of electricity. The authors concluded that the likelihood of substantial initial losses and concerns over the sustainability of sales indicates that private investment capital is unlikely to be attracted. This system was shown to be technically feasible but not economic.

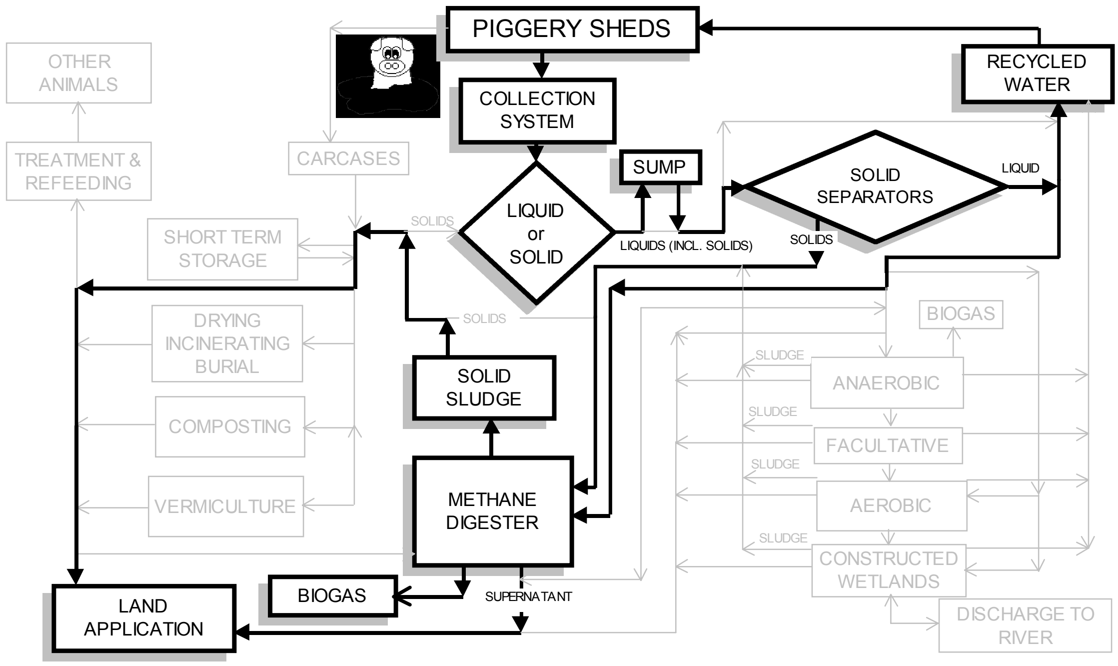


FIGURE 18 - OPTION 8 – ANAEROBIC DIGESTION

7.11 Option 9 – Complete Deep-litter system

One system that completely removes the need for anaerobic lagoons is a deep-litter production system (see Figure 19). The odour reduction benefits of such as system are substantial. About 70-80% of all piggery odour comes from lagoons and the odour emission rate per pig is less in deep-litter systems than conventional sheds. Hence, the odour emission from a complete deep-litter system should be less than 20% of a conventional sheds and lagoons system.

Farran *et al*. (1997) provided cost data on this type of system but their report gives no design or management details.

The advantages of deep-litter systems are low capital cost and, potentially, low odour. However, low odour emission rates are only maintained while the manure /

litter mixture remains aerobic. If the litter becomes wet due to leaking drinkers or external seepage, or if the manure load is too great for the available litter, anaerobic conditions can persist in the sheds and odours can be created. The supply and provision of adequate quantities of litter (straw, sawdust) is an increasing problem for deep-litter systems. This may be a very serious problem during droughts. All-weather access is also critical to the use of these structures.

There are pig performance issues arising with deep-litter systems. It appears that for finisher pigs, non-uniform weight gains are a problem. More stringent nutritional and feeding management is required to overcome these problems. Also, the system is best suited to all-in, all-out production of growing and finishing pigs. The use of deep-litter systems for mating and farrowing is currently being tested, but is yet to be proven.

Hence, while there are clear odour benefits, the adoption of pig production systems based solely on deep-litter sheds is unlikely.

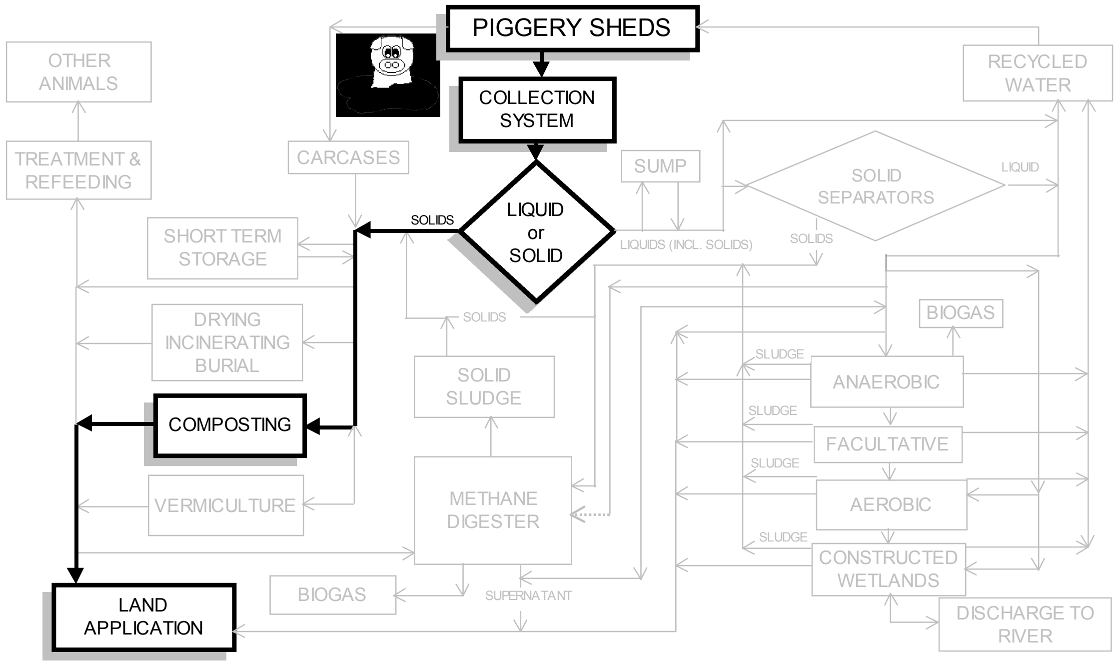


FIGURE 19 - OPTION 9 – COMPLETE DEEP-LITTER SYSTEM

7.12 Option 10 – Combined Anaerobic Lagoon / Deep Litter System

As noted above, deep-litter systems are best suited to the grower / finisher side of pig production. Hence, a viable proposal for a pig production system is to have the breeding herd in conventional sheds (with treatment lagoons) (as in Option 5) and to have the growing pigs in deep-litter systems (as in Option 10). This is shown in Figure 20.

About one third of the total manure production is in the breeder herd. Hence, the anaerobic pond is only one third of the capacity of the pond in Option 5.

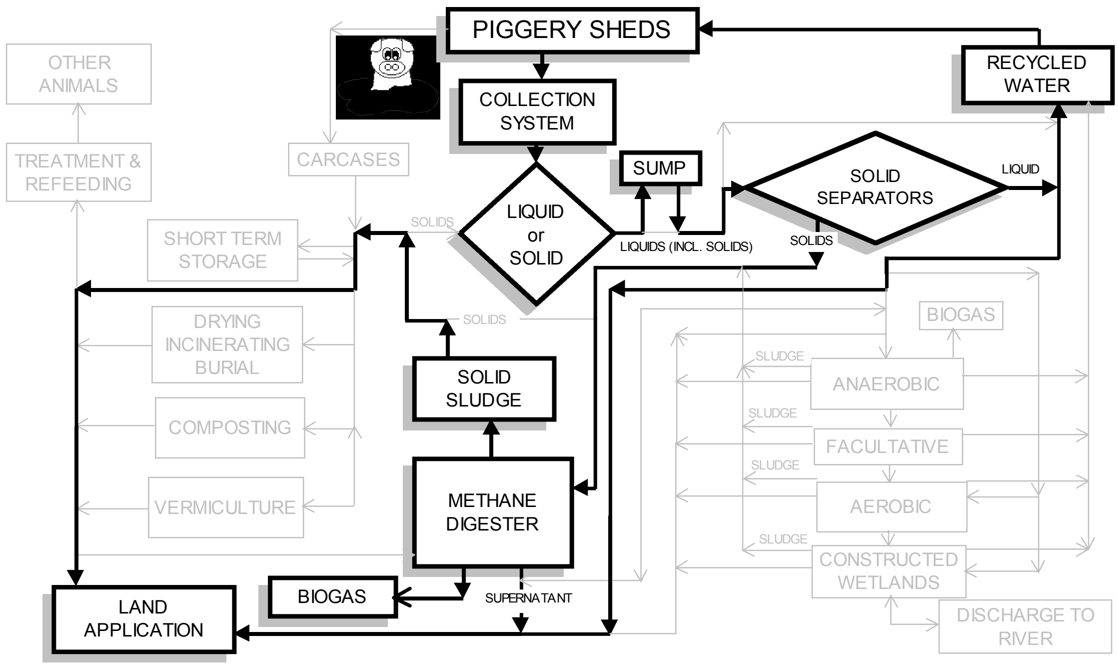


FIGURE 20 - OPTION 10 – COMBINED ANAEROBIC LAGOON / DEEP LITTER SYSTEM

7.13 Option 11 - Surface-aerated Anaerobic Ponds

This option is the same as Option 5 except that the anaerobic pond is surface aerated. This should significantly reduce the odour emission of the piggery but adds capital and operating costs for the aerators. The ponds are designed for a loading rate of 80 gVS/m^3/day. That is, the only benefit of the aerators is odour control.

7.14 Option 12 – High efficiency Solid Separation and Anaerobic Ponds

This option is the same as Option 5 except that the stationary rundown screens have been replaced with centrifuges. The volatile solids removal rate is assumed to increase from 25% to 65%. There is a reduction in the size of the anaerobic pond (with corresponding reductions in odour emission). However, based on Table 1, there is a capital cost increase of about $170,000 for the 2000-sow unit. Operating costs are also increased.

7.15 Option 13 – Anaerobic pond plus Evaporation Pond

The configuration of this system is given in Figure 21. There is no solids separation, no recycling and no effluent irrigation. MEDLI modelling has been used to determine the size of the evaporation pond required to limit overtopping to less than once in every ten years at Murray Bridge. The evaporation pond has a large surface area (and subsequently, large odour emissions). In this option, water use is minimised by reducing flushing to 5 L/pig/day and hosing to 1 L/pig/day.

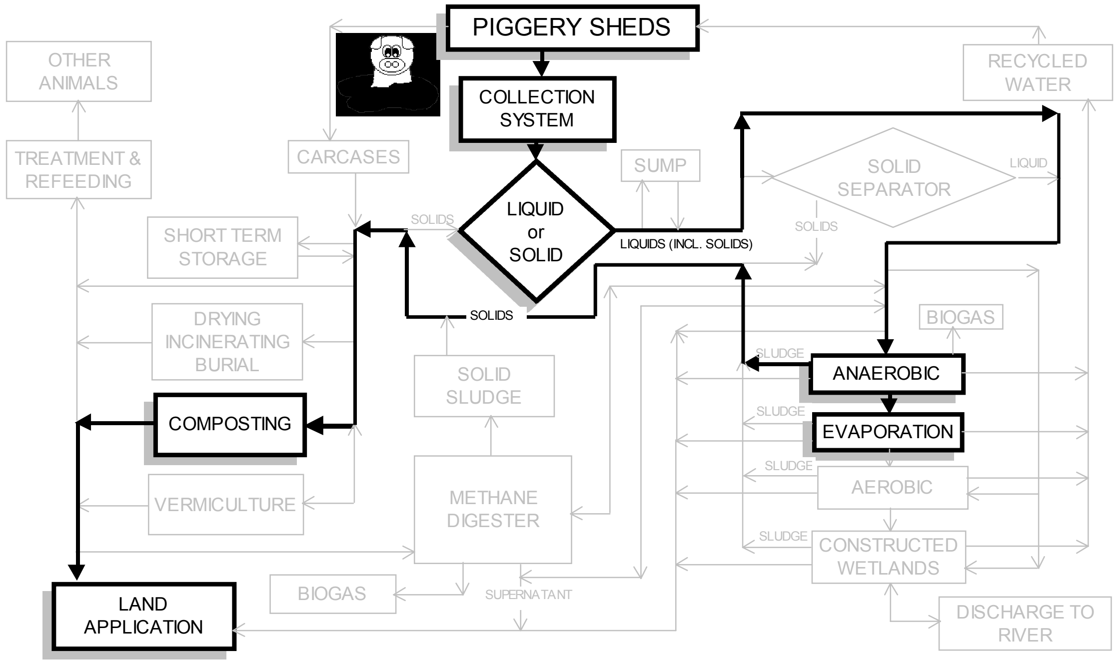


FIGURE 21 - OPTION 13 – ANAEROBIC LAGOON PLUS EVAPORATION POND

7.16 Option 14 – Integrated Floc-based Digester System

Barford (1998, 1999) describes a system of piggery waste treatment using a floc-based sequence batch reactor (SBR). The system was designed and tested at the University of Sydney and a pilot plant was installed at Hillcrest Park pig farm, Menangle, NSW.

The idea is to operate a batch reactor under a sequence of aerated and non-aerated conditions, so that organic matter as well as ammonium, nitrate and phosphate can be removed sequentially and sometimes simultaneously. Such a system is simple as it only consists of one digester tank. The technology is used in domestic sewage treatment and treatment of other organic wastes (e.g. abattoirs). BOD reduction (60% reduction in COD) and nitrogen removal (99.9% reduction in NH_4^-) are the benefits.

The system is far more complex than a simple anaerobic pond. There are several operations such as drawing, filling, settling, aeration and non-aeration within the digester. These can be controlled by electric timers. As with all systems that use aeration processes, performance is completely dependent on the continuous operation of the aerators and other equipment. Hence, a high level of supervision and maintenance is required. For example, during testing at Hillcrest, an influent pump failed. This caused bacteria to die and caused on-going reductions in the SBR's performance. After 6 weeks, it was discovered that the SBR's overflow pipe had blocked due to a white precipitate. This is struvite and is a very common problem in piggeries. (Struvite is one reason for simple waste treatment systems with few pipes and pumps.)

Barford (1998, 1999) does not provide enough technical or economic information to allow a comparison with the other options in this report. However, they claim that for a 20,000 pig unit, the capital cost of the SBR would be $267,000. This presumably

does not include the cost of other components of the waste system (holding ponds, irrigation, solids handling). The operating cost appears to be about $150,000 per year.

7.17 Returns from Effluent Treatment Systems

The returns from piggery effluent treatment systems vary from nothing when effluent is simply flushed into ponds and allowed to evaporate away to significant returns if effluent is treated, packaged and marketed. Agribiz Engineering (1999) has recently completed a study of conventional and innovative options for adding value to piggery wastes. Table 6 and the following discussion is taken from that study.

TABLE 6 – SUMMARY OF DIFFERENT METHODS OF VALUE ADDING TO PIGGERY WASTE

(taken from Agribiz Engineering, 1999)

Product	Grams of product per kg meat* produced	Value Cents/kg meat	Production and/or handling costs Cents/kg meat	Net Return Cents/kg meat
Fertiliser Replacement				
100% recovery	108	14.0	2.2-3.9	10.1-11.8
Fertiliser Replacement - Field Practice – 30% recovery				
Tanker	66	4.7	2.4-3.7	1.0-2.3
Irrigation	66	4.7	1.5-4.4	2.0-3.1
Biogas and Solids				
Enclosed Digester		21.9	16.2	5.7
Covered lagoon		10.9	10.0	0.9
Vermicompost @ 50% moist. Content & 15% recovery	260	5.2	0.7	4.5
Compost				
100% recovery				
Bagged	2900	27.5	7.0	20.5
Bulk	2900	5.0	2.9	2.1
30% recovery				
Bagged	870	8.4	2.1	6.3
Bulk	870	1.5	0.9	0.6
15% recovery				
Bagged	435	4.1	1.1	3.0
Bulk	435	0.8	0.4	0.4
Innovative Uses				
Feedstuff	786	6.3	5.6	0.7
Yeast	29.8	1.8	12.5-14.5	-11.7
Spirulina	6.5	0.4	7.4	-7.0
Aquaculture	10.2	1.5	12.8	-12.4

* based on 9.16 kg of manure produced per kg pigmeat (carcass weight) produced.

In summary, Agribiz Engineering (1999) concluded:

- Applying the wastes directly to land as fertiliser replacement offers the best method of adding value, provided that the site has soils and rainfall (irrigation) to adequately use the nutrients provided.
- There is potential to capture the solids from the waste stream, compost them with other carbon-type materials and package the product in 30 L bags. Location may be a limitation with respect to transport and sources of other waste materials for composting.
- There is potential to make an additional $50-$200 per sow per year from the better use of wastes generated in the piggery.
- The current use of lagoon systems with little use of the lagoon effluent and sludge may be costing up to $50 per sow per year.
- For larger piggeries, more than 11,000 pigs, the use of totally enclosed anaerobic digestion with electricity generation, bagged solids and liquid nutrient use has been shown to be economically and technically viable (i.e. Berrybank).

8 COMPARISON OF EFFLUENT TREATMENT OPTIONS

The various effluent treatment options described in Section 7 have been analysed and compared.

The design of a piggery effluent treatment system is site-specific. Numerous assumptions were made to allow the options to be designed and analysed. The assumptions include:

- Except for deep-litter system, all pigs are housed in conventional sheds with under-floor flushing.
- Except for Option 13, the flushing volume used was 20 L/pig/day and the hosing used was 2 L/pig/day. As noted previously, this is probably an over-estimate for system where recycling is not used.
- When solids are removed from the effluent stream, it is assumed that a stationary rundown screen is used (except Option 12). This screen removes 8% of nitrogen, 11 % of phosphorus, 25 % of volatile solids and 20 % of total solids.
- The irrigation area needed was the maximum required to satisfy either the hydraulic load, the nitrogen load or the phosphorus load. The limited loads were 4 ML/ha/yr for water, 200 kg/ha/year for nitrogen and 50 kg/ha/yr for phosphorus. These limitations are very site-specific.
- Gross odour emission rates were estimated using the methods outlined in Watts (1999a, 1999b) with a number of assumptions needing to be made where data does not exist. The odour only includes sheds and lagoons. It does not include odour emitted during effluent irrigation or spreading of slurry or compost. The odour emissions are only approximate and are expressed as a percentage of the maximum odour emitting case.
- Capital costs were based on the data given by Farran *et al*. (1997) and modified as deemed appropriate. The data given by Farran *et al*. (1997) is not clearly described and assumptions had to be made. It is assumed that in their capital costing, the cost of purchasing land for effluent irrigation is not included. It is assumed that the farm has sufficient land.
- It is assumed that all solid by-products (effluent screening, carcasses, lagoon sludge) are composted with a bulking agent (such as sawdust) and then sold off-site.

The performance of each option was compared via a number of key indicators. These are:

- Fresh Water Use (ML/yr)
- Total pond capacity (anaerobic plus secondary) (ML)
- Annual irrigation (ML/yr)
- Irrigation area required (ha)
- Off-site compost sales (t/yr)
- Odour emission (% of maximum option)
- Capital cost per SPU
- Operating cost per SPU
- Annual cost (operating plus capital) per SPU

Performance could also be expressed on the basis of meat production. Meat production of 2000-sow piggery is 3540 t/yr dressed weight. Manure production is 8.8 kg per kg pigmeat produced.

Figures 22 to 39 compare the various options according to these key indicators. Some further explanation are necessary.

- Fresh Water Use

The use of recycling reduces fresh water requirements by about one third (assuming the same flushing requirement). Option 13 (no recycling but low flushing volume) uses about the same fresh water as systems using large flushing volumes and recycling.

- Total pond capacity (anaerobic plus secondary)

The largest total pond capacity is Option 13. This is due to the size required for the evaporation pond to limit overtopping to an acceptable frequency. Some options (1, 2, 8, 9) have no ponds (with a subsequent reduction in odour emission).

- Annual irrigation

The largest amount of on-farm irrigation occurs for options where recycling of treated effluent does not occur.

- Irrigation area required

By far, the largest on-farm irrigation areas required are Options 1 and 2. In these cases, most of the nutrients is applied to land on-site. Hence, large areas are required to achieve environmental sustainability. This is probably the reason why these options would not be suitable for a large piggery. For the 2000-sow unit, over 1000 ha (2500 ac) of good agricultural land is required adjacent to the piggery.

- Off-site compost sales

The largest amounts of off-site compost sales occur with Options 9 and 10. These are the systems based on deep-litter production. The limitations of these options are the ability to reliably purchase straw and the availability of off-site farms to purchase the compost.

- Odour emission

The largest odour emissions are predicted for Option 13 due to the large pond surface areas. The three options using conventional anaerobic ponds (3, 4 & 5) produce significant odour. The least odour is produced with the deep-litter systems. Options 1 and 2 apparently have little odour but the data in these figures only takes account of shed and pond emissions. Unless direct injection is used, the spreading of manure slurries under all weather conditions can result in significant odour.

- Capital cost per SPU

By far, the most costly scheme is the Berrybank-style anaerobic digester and co-generation system. This system can only be viable if the electricity generated is sold at a reasonable price. The covered anaerobic pond is the next most expensive option.

- Operating cost per SPU

As well as Berrybank, the mechanically-aerated options have high operating costs. This is due to the power requirements of the aerators as well as the labour and repairs and maintenance costs.

- Annual cost (operating plus capital) per SPU

The annual cost is the operating cost plus the amortised capital cost. Clearly, the anaerobic digester is the most expensive option.

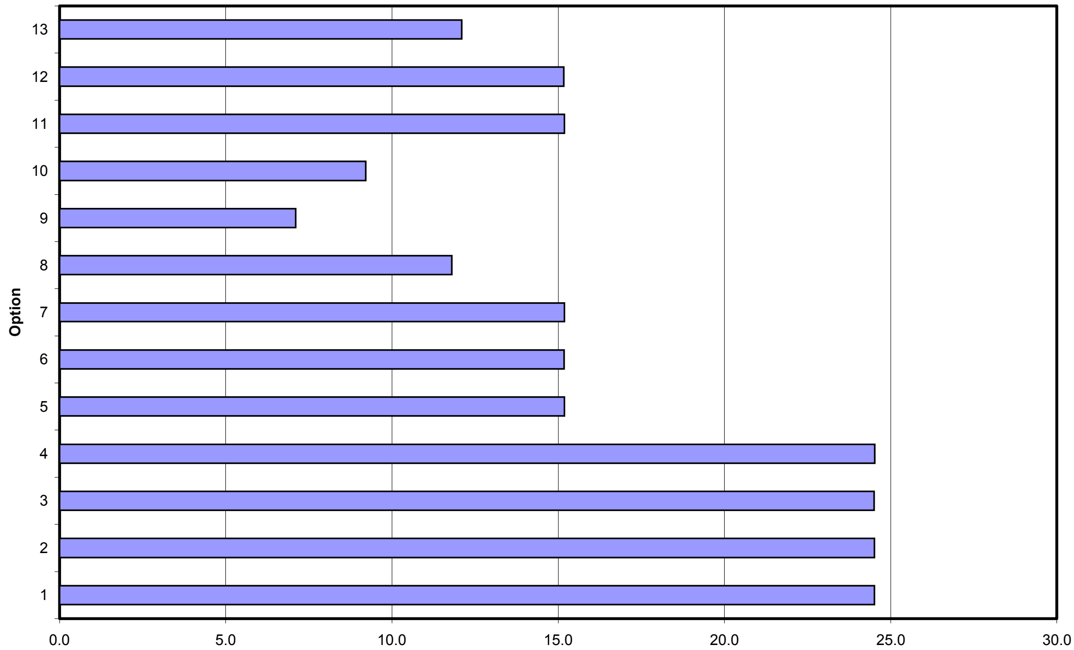


FIGURE 22 - FRESH WATER USE (ML/YR) - 200-SOWS

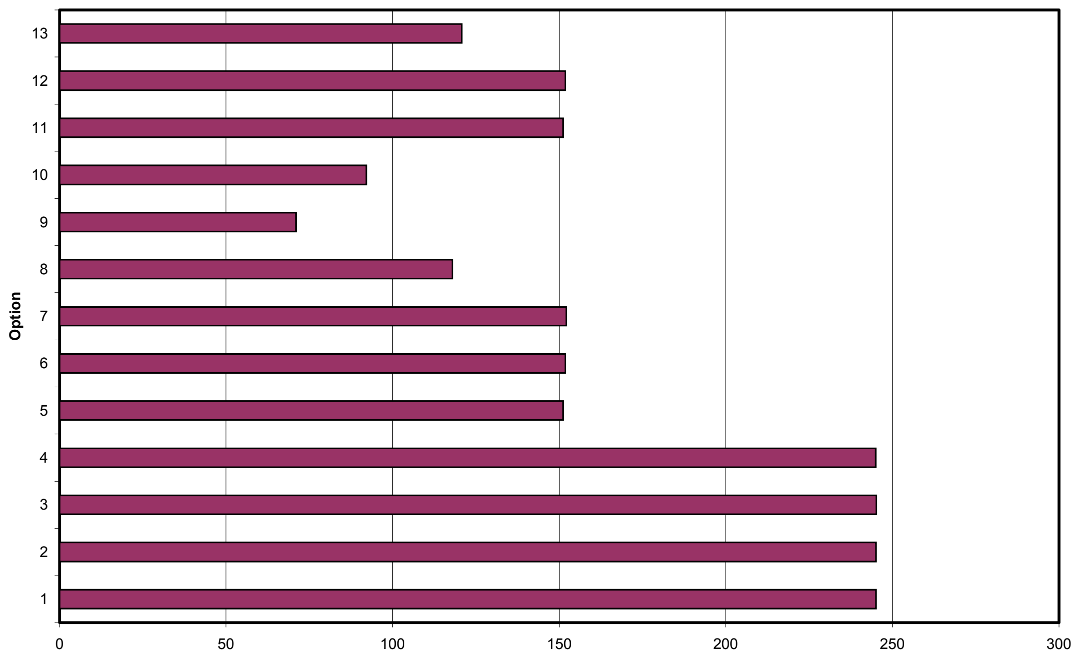


FIGURE 23 - FRESH WATER USE (ML/YR) - 2000-SOWS

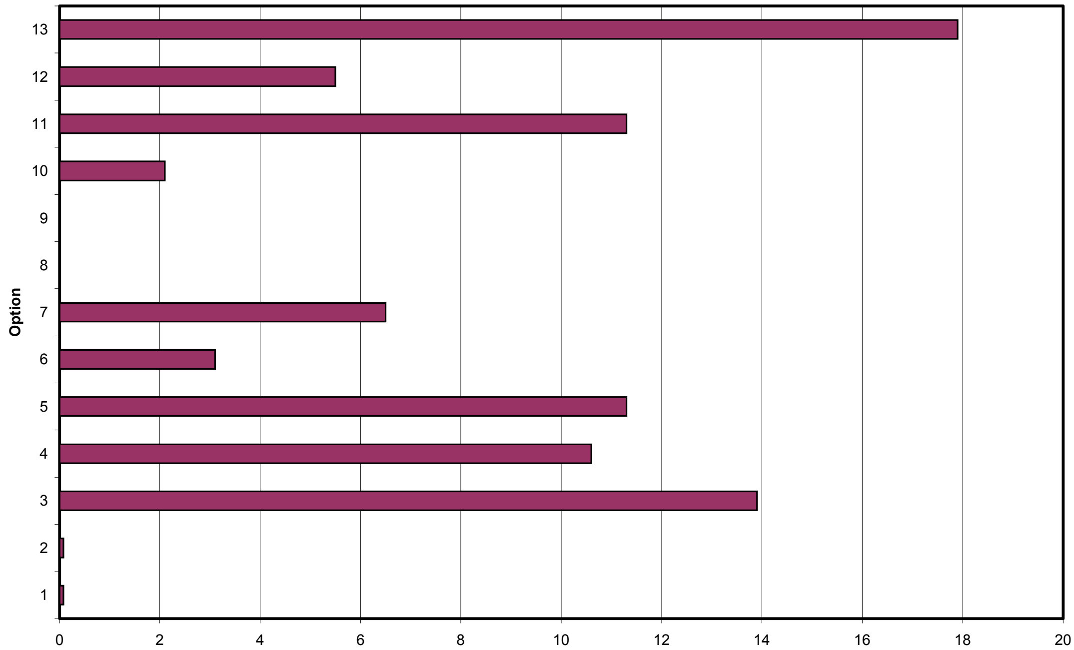


FIGURE 24 - TOTAL POND CAPACITY (ML) (200-SOW)

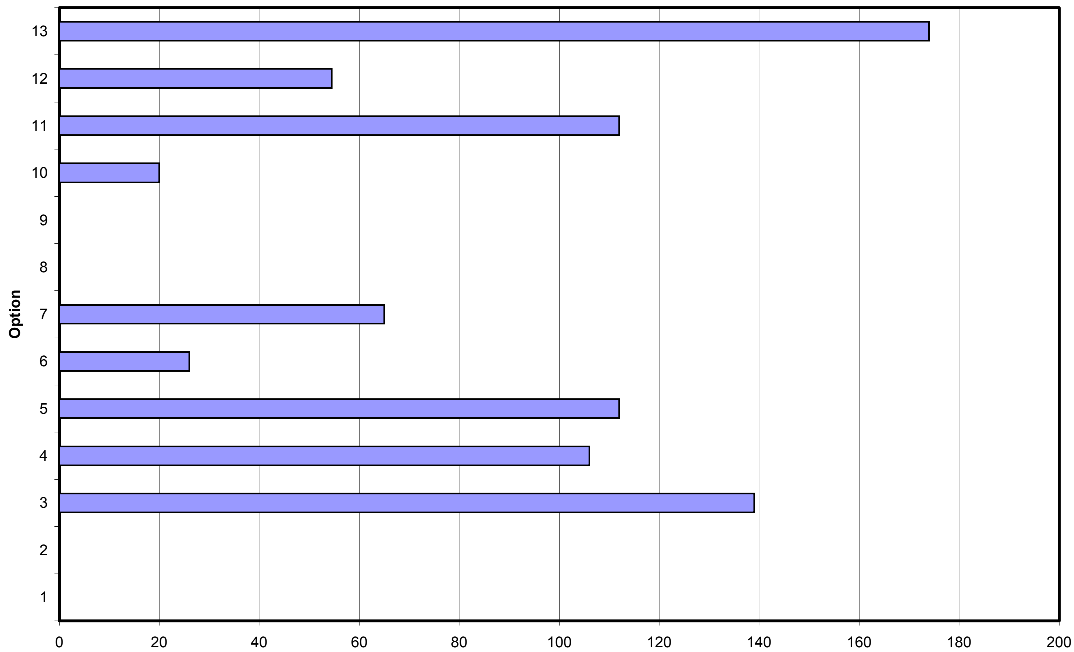


FIGURE 25 - TOTAL POND CAPACITY (ML) (2000-SOW)

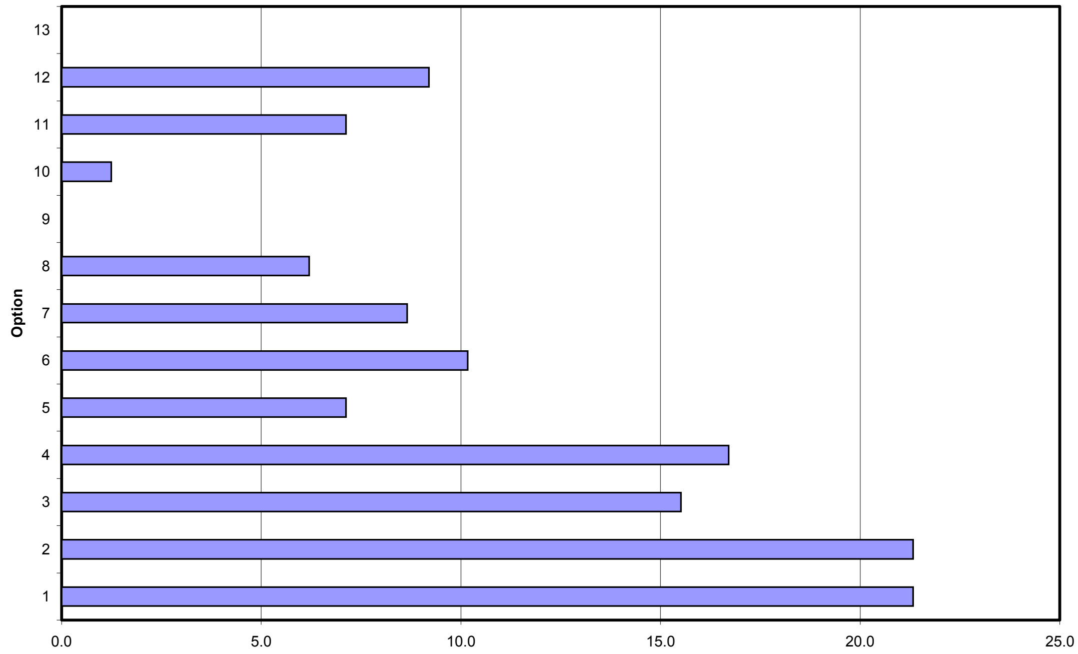


FIGURE 26 - ON-FARM EFFLUENT IRRIGATION (ML/YR) - 200-SOWS

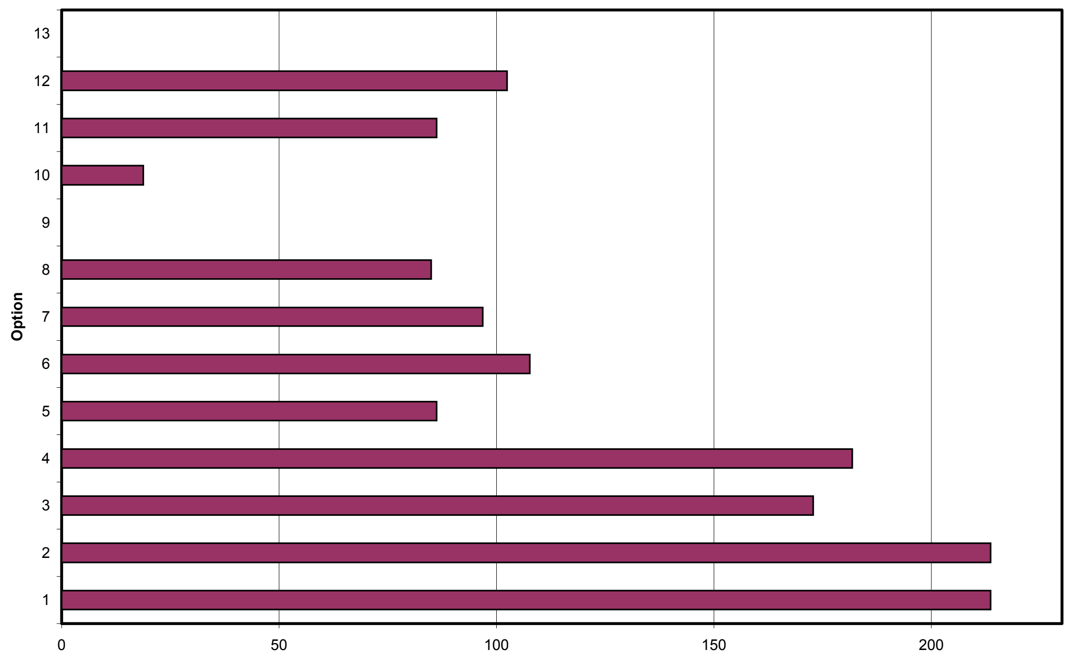


FIGURE 27 - ON-FARM EFFLUENT IRRIGATION (ML/YR) - 2000-SOWS

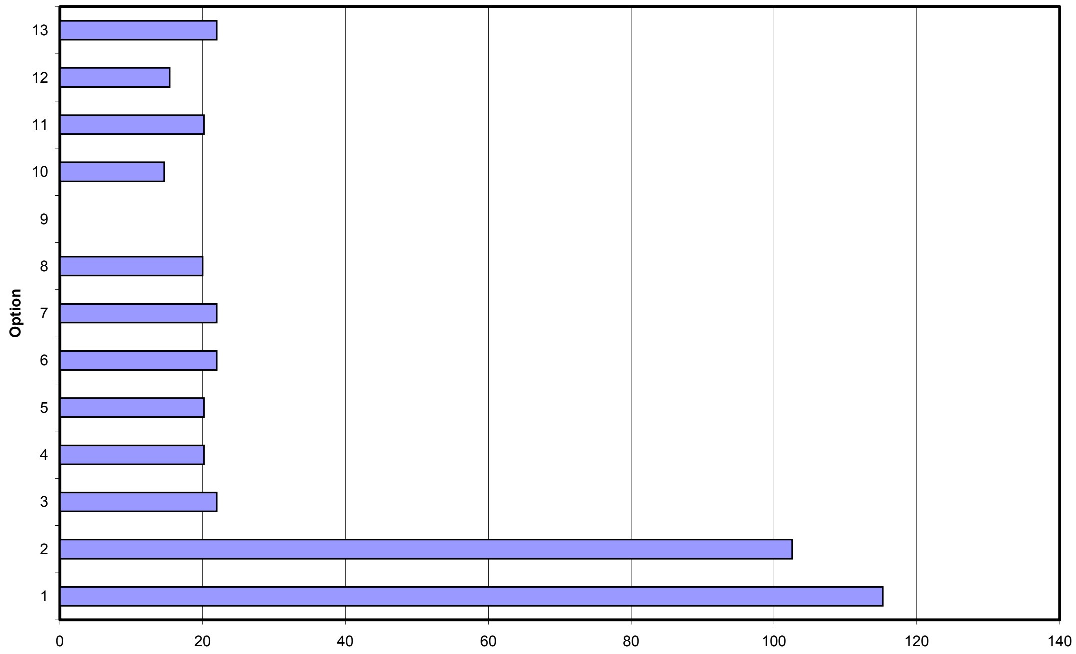


FIGURE 28 - ON-FARM IRRIGATION AREA (HA) - 200-SOWS

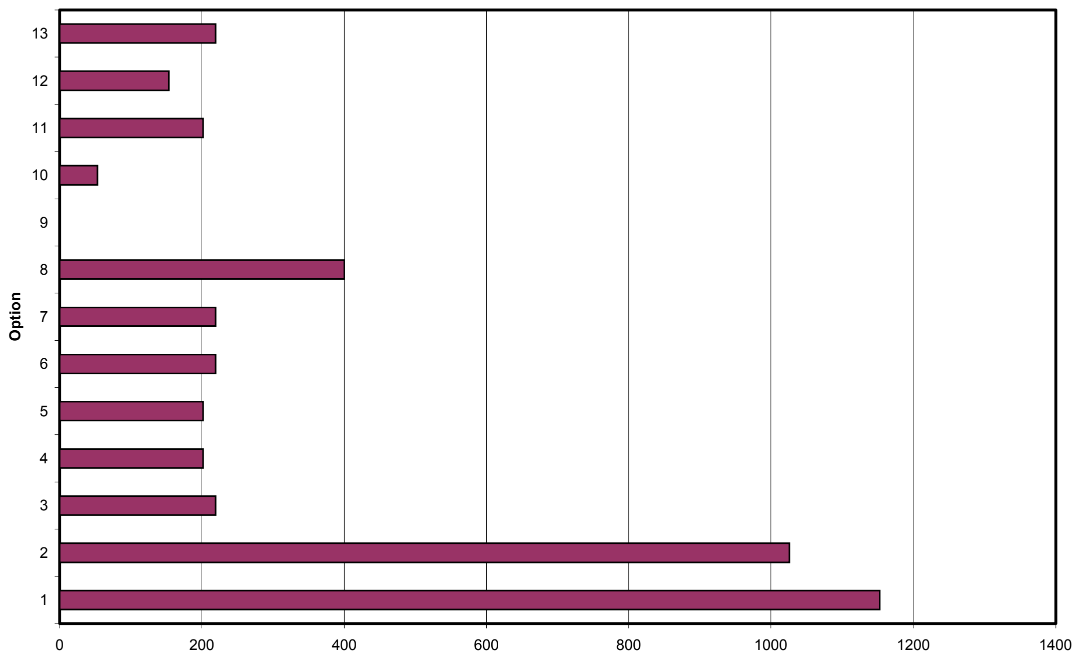


FIGURE 29 - ON-FARM IRRIGATION AREA (HA) - 2000-SOWS

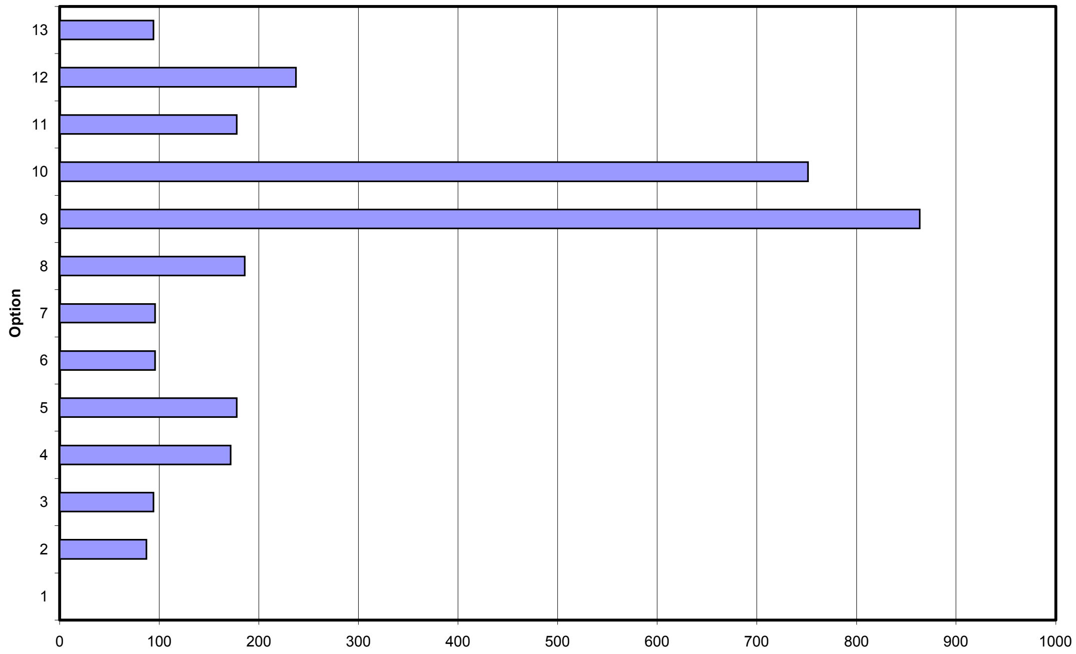


FIGURE 30 - OFF-FARM SOLIDS SALES (T/YR) - 200-SOWS

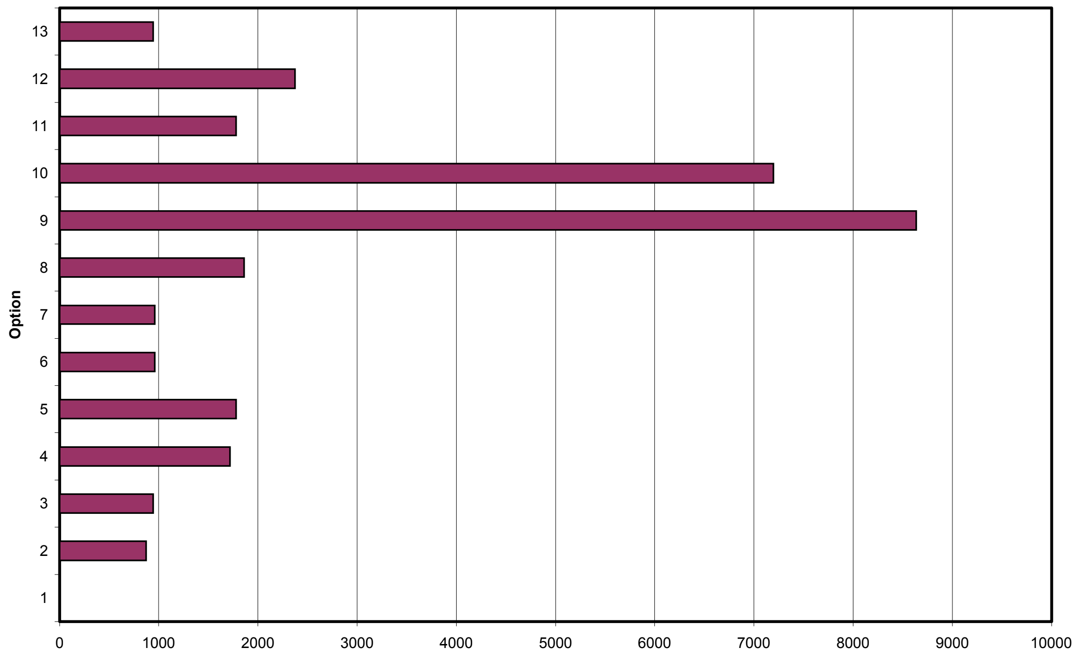


FIGURE 31 - OFF-FARM SOLIDS SALES (T/YR) - 2000-SOWS

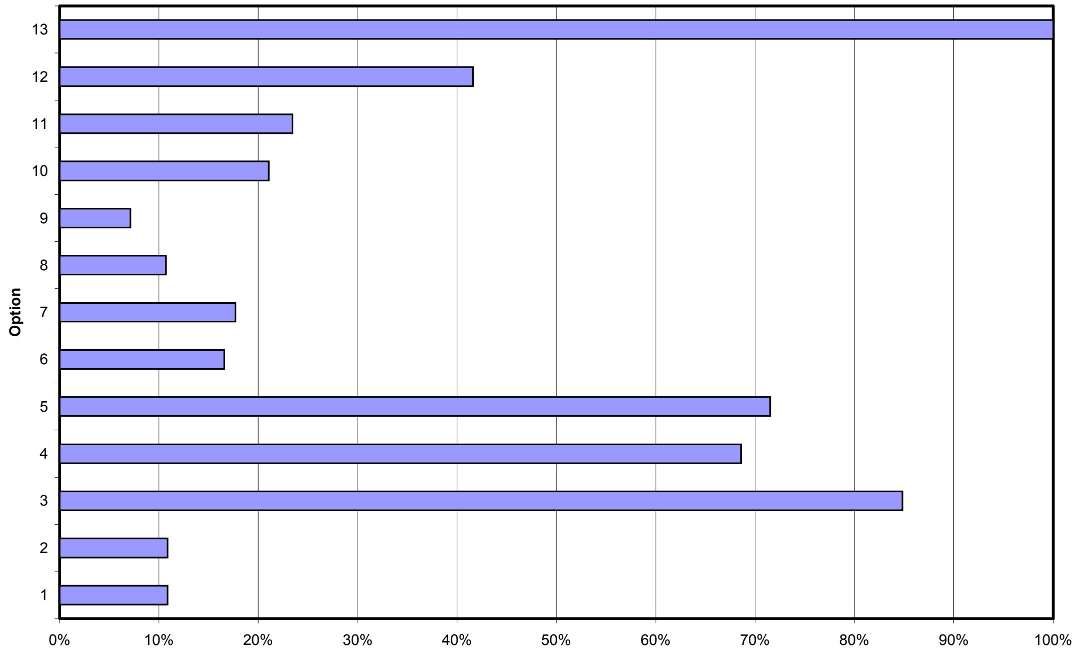


FIGURE 32 - RELATIVE ODOUR EMISSION (SHEDS & PONDS) - 2000-SOWS

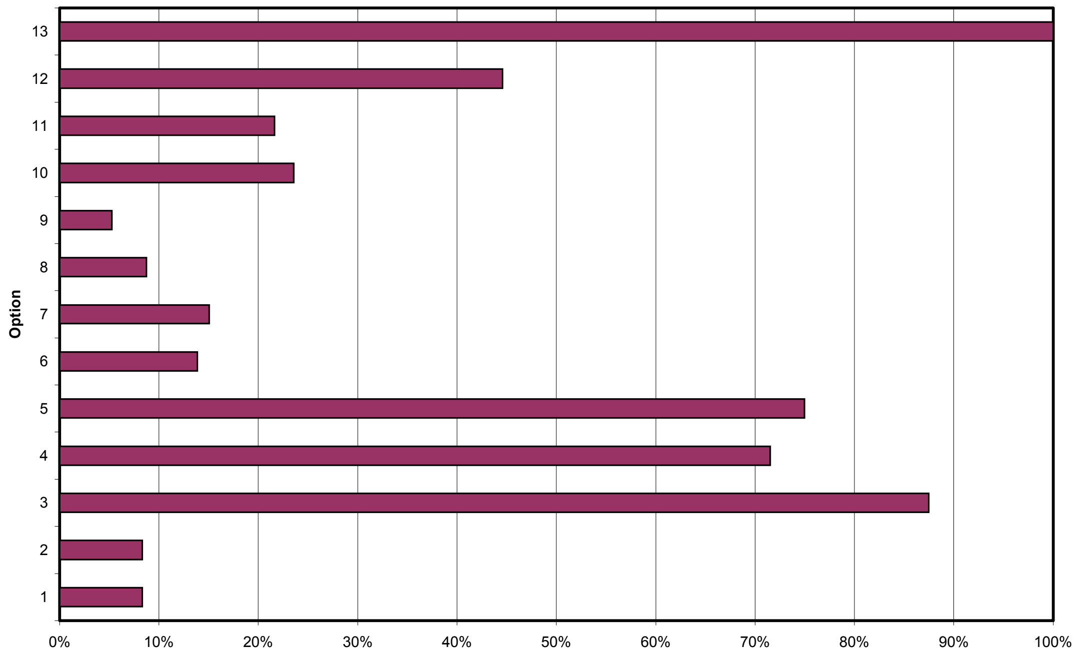


FIGURE 33 - RELATIVE ODOUR EMISSION (SHEDS & PONDS) - 200-SOWS

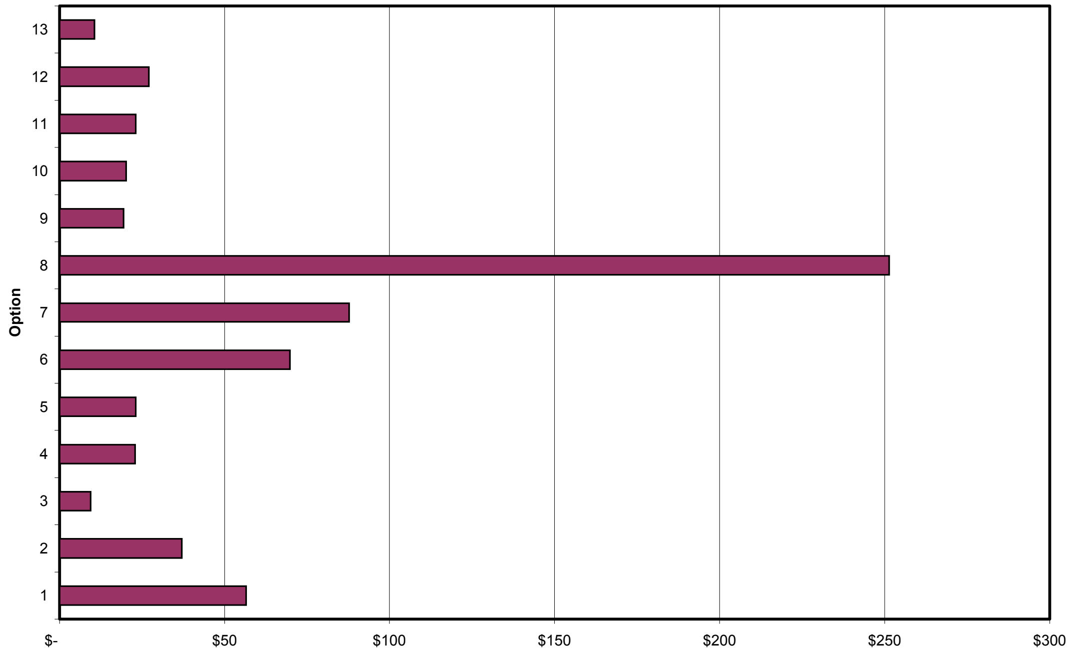


FIGURE 34 - CAPITAL COST PER SPU (200-SOW)

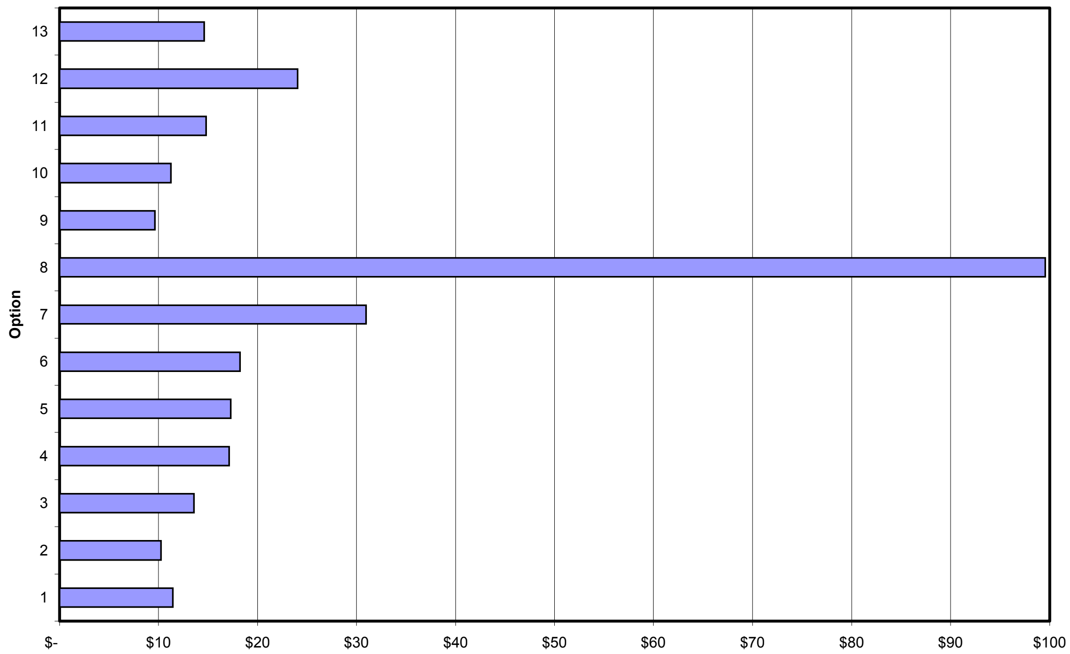


FIGURE 35 - CAPITAL COST PER SPU (2000-SOW)

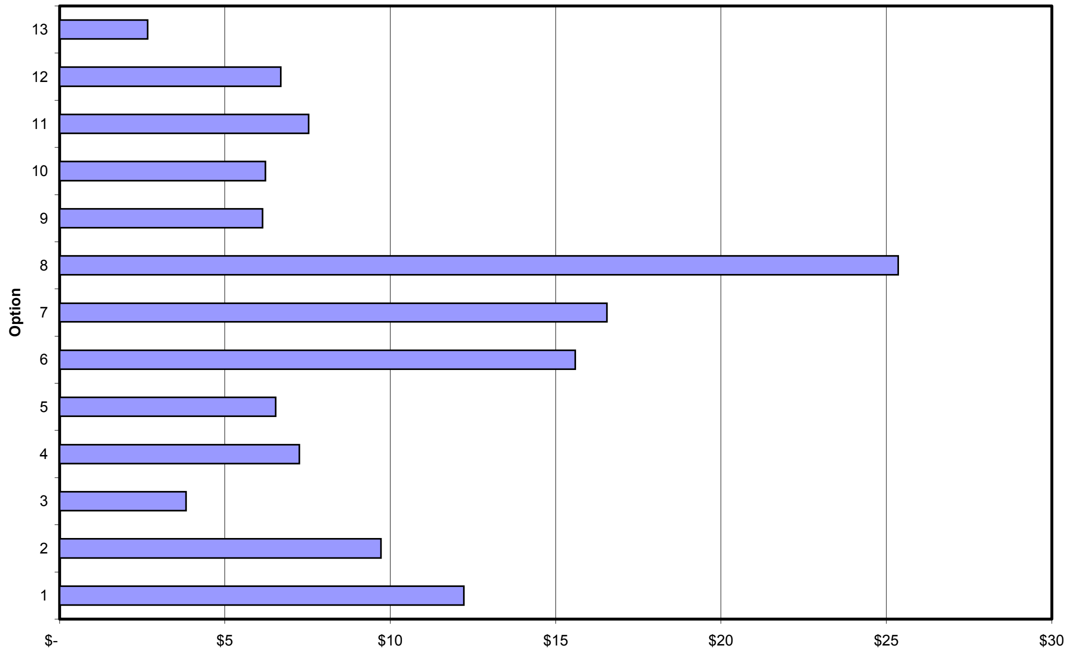


FIGURE 36 - OPERATING COST PER SPU (200-SOW)

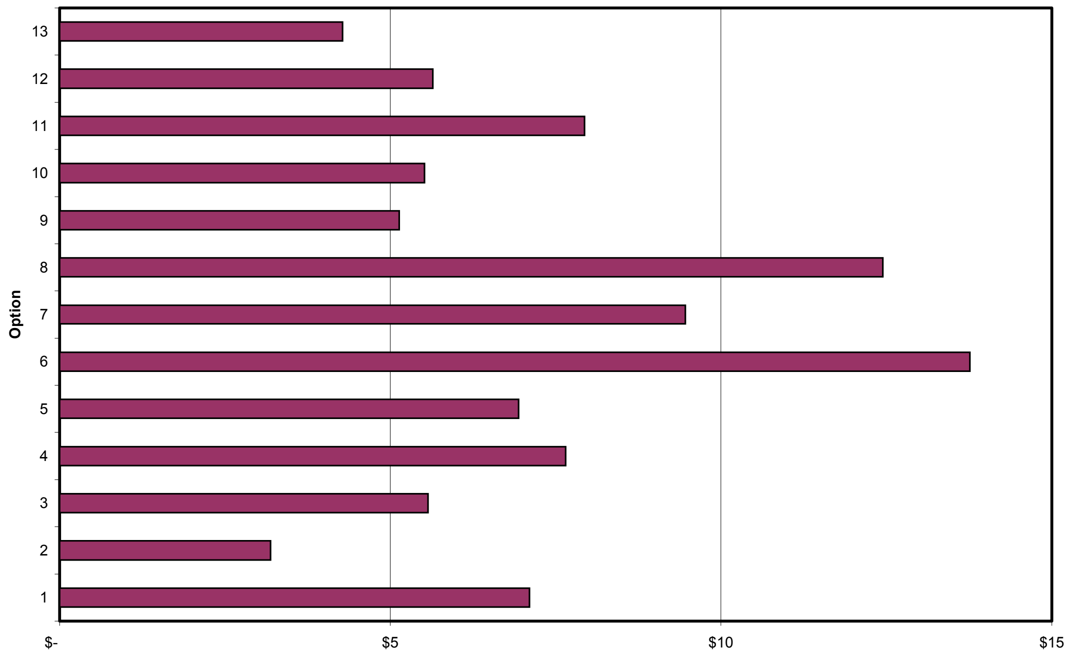


FIGURE 37 - OPERATING COST PER SPU (2000-SOW)

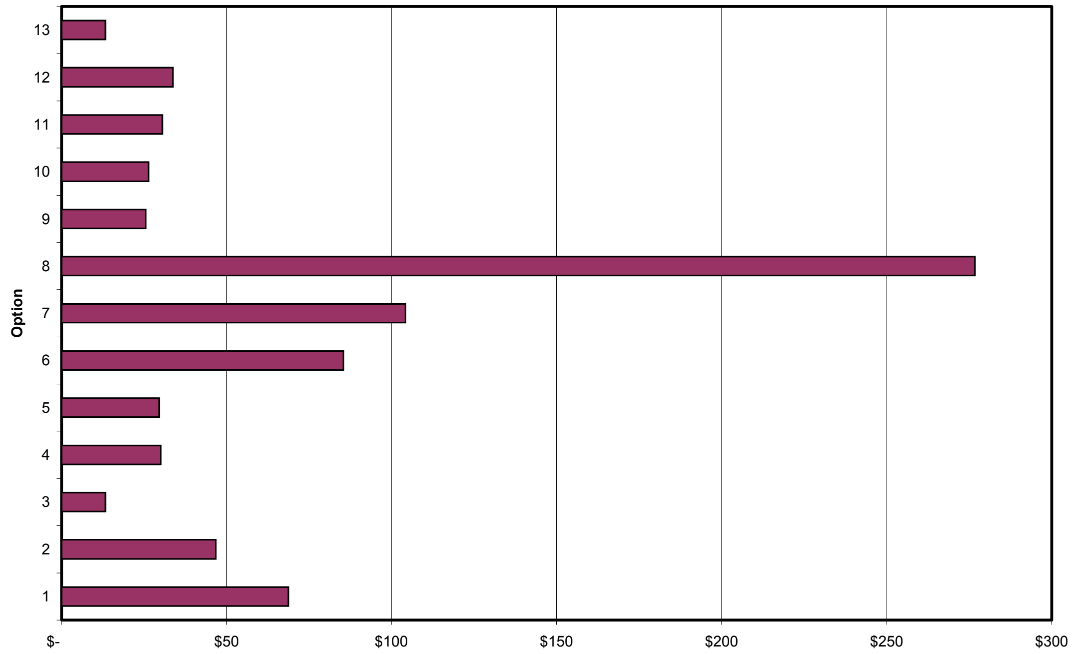


FIGURE 38 - ANNUAL COST PER SPU (200-SOW)

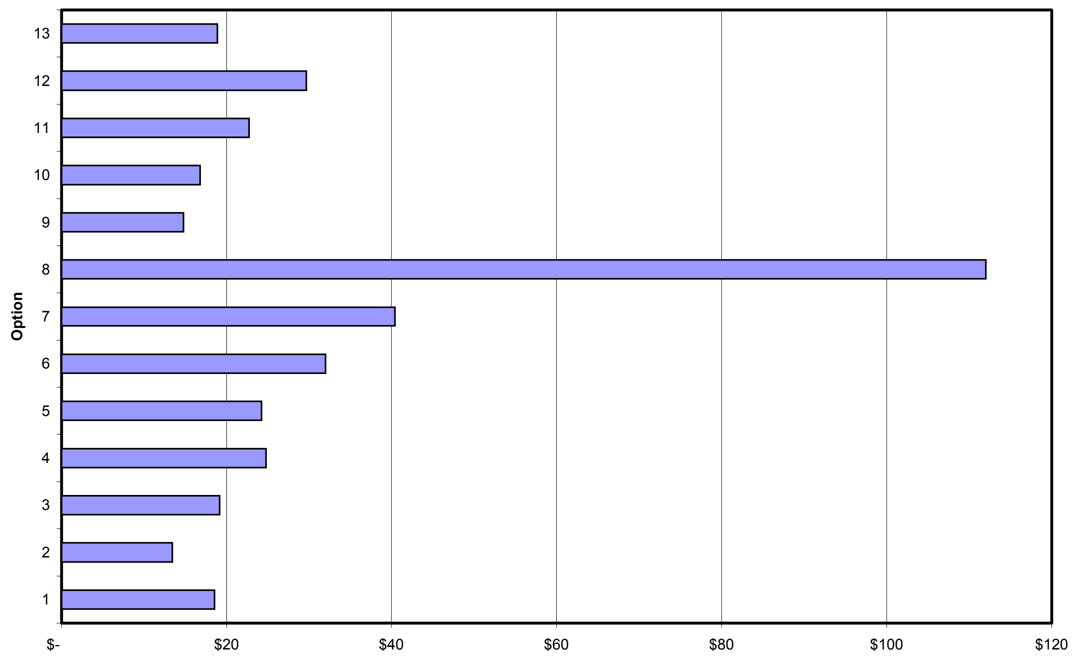


FIGURE 39 - ANNUAL COST PER SPU (2000-SOW)

9 MURRAY BRIDGE LOCALITY

Murray Bridge is rural city located about 60 km east of Adelaide, or 78 km drive along the South-Eastern Freeway. The city has a population of about 13,500, with a district population of about 17,000. The area of the district is 177,200 ha.

The longitude and latitude are 139816’ and 3587’, respectively. The mean annual rainfall is 347 mm, or almost 14 inches. Details of historical monthly rainfall data are provided in Figure 40 and Table 7. Mean monthly temperatures range from 148 minimum to 288 maximum in the summer; and 68 minimum to 178 maximum in the winter. The average humidity is 68% at 9 AM, falling to 45% at 6 PM. The main street of the city is located 25 m above sea level, although parts of the city are 14 m or less above sea level (South Australia Superb Websites Ring 2000).

Agriculture is an important component of the regional economy. Agriculture ranges from intensive horticulture, floriculture and viticulture to extensive cropping and livestock production. About 25% of South Australia’s total pig production, 20% of the states dairy production and a significant component of the poultry production is located within the area (South Australian Regional Development Association 1999).

According to Meo and Cleary (1999), in June 1998, 16% of Australia’s sows were located in South Australia. This equated to 644 herds with a total of 47,652 sows. About two-thirds of the herds had less than 50 sows, with only 13 having over 400 sows. Based on these statistics, it appears that about 11,900 sows, or 131,000 pigs, are located within the Murray Bridge area. It is unclear how many herds are located within the area, since there could be a disproportionate number of large (or small) piggeries in the locality.

According to Chris Harris (Department for Environment and Heritage, pers. comm. 5 April 2000) most of the piggeries in the Murray Bridge area use conventional flushing or static pits combined with effluent treatment in anaerobic lagoons and disposal via evaporation basins. Some of the new large piggeries use pull plug systems, coupled with anaerobic lagoons and evaporation basins. There is limited screening of effluent from piggeries. Because the climate is quite dry, there is limited irrigation from lagoons. Sometimes contractors are engaged to draw effluent from the lagoons and to spread it using large vacuum tankers. However, some piggeries irrigate effluent with or without solids separation and without lagoon treatment. Large vacuum tankers are often used to spread this effluent. There are only a few ecoshelters in the area.

TABLE 7 – RAINFALL DATA FOR MURRAY BRIDGE

Probabilities of monthly rainfall recorded at MURRAY BRIDGE POST OFFICE
Amounts of rain (mm) received or exceeded in 100%, 90% ... 0% of years.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr
Lowest on record	0	0	0	0	2	5	1	3	2	2	0	0	137
90% yrs at least	1	1	1	4	9	10	13	15	11	7	4	3	245
80% yrs at least	3	2	3	8	15	16	21	21	17	13	8	6	268
70% yrs at least	5	3	6	15	20	24	23	25	23	19	12	9	293
60% yrs at least	7	6	7	19	28	29	27	30	29	22	18	12	314
median, 50% yrs	10	10	11	23	32	34	33	35	35	30	21	15	341
40% yrs at least	14	15	15	27	39	40	36	39	42	35	24	20	364
30% yrs at least	19	19	21	36	45	48	43	44	46	43	29	26	380
20% yrs at least	27	28	31	43	50	55	51	52	55	51	42	35	405
10% yrs at least	40	47	52	61	65	69	60	59	62	67	52	47	475
Highest on record	190	129	169	189	113	88	103	117	93	136	87	130	677
Mean	17	18	20	29	35	37	35	37	36	34	25	23	347
Standard deviation	22	24	26	26	22	21	18	18	20	24	19	23	92

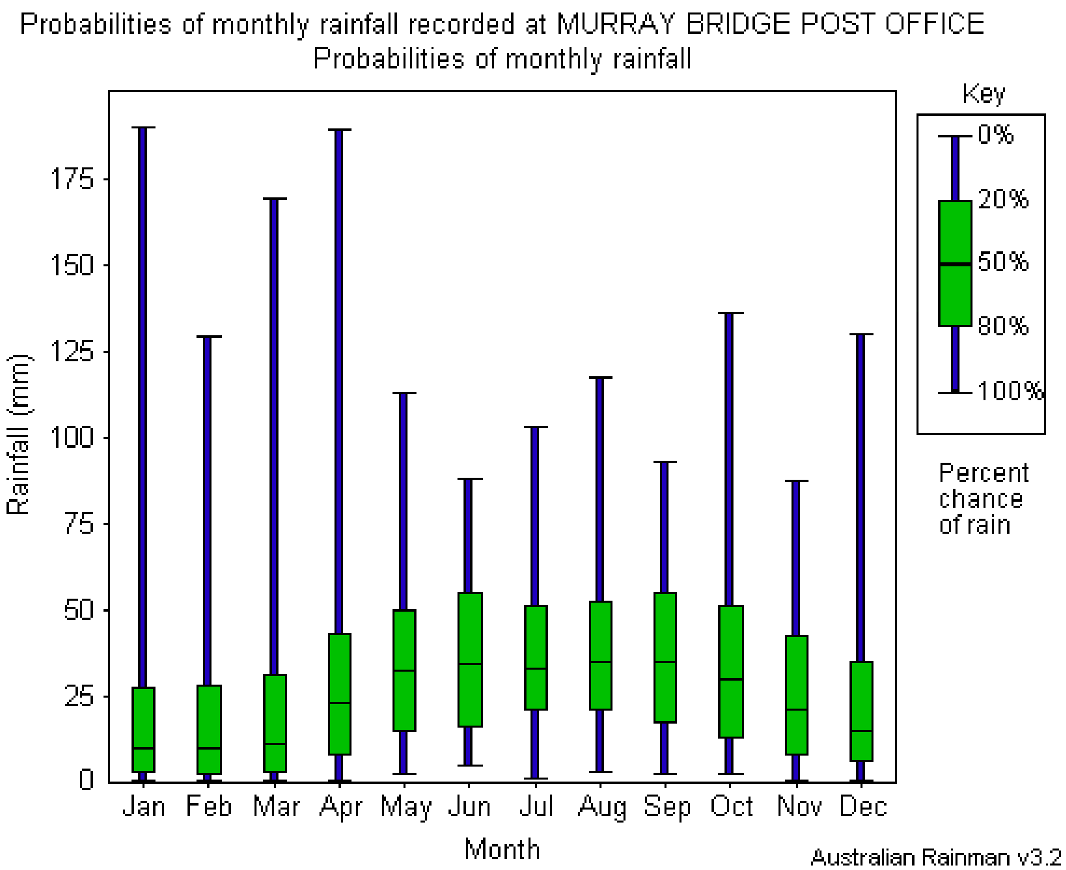


FIGURE 40 – RAINFALL PROBABILITIES FOR MURRAY BRIDGE

10 CONCLUSIONS AND RECOMMENDATIONS

Piggery waste treatment systems need to sustainably treat or dispose of large quantities of organic matter, nutrients and salts. There are many options for the design of a treatment system ranging from simple systems where virtually no treatment occurs to complex and costly systems that completely treat all of the waste and optimise the returns that can be achieved from that waste.

The system chosen for a particular site is dependent on:

- Local climate
- Environmental constraints
- Final utilisation site of nutrients
- Capital costs
- Operating costs
- Labour requirements
- Convenience
- Technical requirements

When assessing each of the thirteen options analysed according to the various key indicators, each option has some advantages and disadvantages. Without site-specific knowledge, there is no clear choice as to the best system. Close proximity of neighbours would result in a different optimum solution compared to a site where on-site land availability is an issue.

Odour is a particular issue in the Murray Bridge area. Hence, those options with the least odour emission are preferred. In particular, the option that combines the breeding herd in conventional sheds and the grow-out herd in deep-litter systems is attractive. However, not all producers are satisfied with the herd performance in deep-litter systems. If conventional anaerobic ponds are to be used, surface aeration may be the most cost-effective method of odour reduction but the ponds should be designed to function satisfactorily without aeration. This then caters for aerator breakdowns. Using current knowledge about pond emissions, the use of evaporation basins with large surface areas seems to produce too much odour.

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APPENDIX A – TYPICAL PIGGERY

To assess odour reduction strategies, data for "typical" piggeries are needed. This appendix provides this data. There are many different designs possible for piggeries and their effluent treatment systems. The typical system described below applies to a modern piggery in Queensland. In other areas of Australia, the use of large treatment lagoons with recycling of treated effluent for flushing is less common.

The herd structure and effluent production of typical 200-sow and 2000-sow herds were analysed using a modified version of PIG-BAL, a spreadsheet developed by the Queensland Department of Primary Industries. Table 8 shows the number and liveweight of each class of pigs in the 2000-sow piggery. The data for the 200-sow piggery is 10% of the data in Table 8. It is assumed that pigs are weaned at 3 weeks and are sold at 23 weeks at a liveweight of 110 kg. Mortalities, litter size, etc. are typical (not high-performance) data. Table 9 shows the manure production (total solids, volatile solids, nutrients) for each class of pigs. Manure production is estimated using a modified version of DAMP analysis (Barth 1985). This data remains constant for all the 2000-sow piggery options listed in this report.

In these typical piggery units, pigs are housed in naturally-ventilated conventional Australian sheds. The pens have partially or fully-slatted floors. Manure and waste feed fall through the slats into a concrete channel beneath the pens. The channels are flushed daily. Hosing removes feed and manure that do not fall through the slats. It is assumed that the flushing and hosing volumes are 20 L/pig/d and 2 L/pig/d respectively. The manure and spilt feed are flushed into a three-lagoon treatment system. No solids removal occurs between the flushing channels and the primary lagoon. The first lagoon is the primary treatment area where anaerobic digestion of the effluent stream occurs. This lagoon is sized on the basis of organic loading rate (80 g VS/m^3/day) for its active capacity plus a 40% provision for sludge accumulation (allowing about 10 years before desludging). (VS are volatile solids). This results in a lagoon volume of 133 ML, which represents 6.7 m^3/pig. Experience has indicated that this relatively large treatment volume per pig is required to ensure that odour emissions from the primary treatment lagoon are acceptable. The lagoon is 5 m deep. It is assumed that this lagoon removes 85% of incoming volatile solids.

Treated effluent then flows into a secondary lagoon. This lagoon is also sized on the basis of 80 g VS/m^3/day. There is no provision for sludge accumulation. Based on our experience, it is assumed that this lagoon removes only 50% of incoming volatile solids.

A third lagoon acts as a polishing lagoon prior to effluent irrigation. About 75% of the flushing water used in the piggery is recycled from this lagoon. A wet-weather overflow lagoon is provided to cater for periods when irrigation is not possible.

For the 2000-sow piggery, it is assumed that it is operated as two back-to-back 1000-sow units. With this system, the lagoon system is duplicated. Hence the lagoons are each sized for a 1000-sow unit. The sizes of the lagoons for both units are summarised in Table 10.

These are typical design parameters for new piggeries in Queensland where odour nuisance is not a major issue. The advantages of the system are:

- Daily channel flushing is a convenient, low-labour method of manure removal.

- Recycling of treated effluent as flushing water reduces the total clean water demand of the piggery and removes any impediment to frequent flushing (and subsequent clean sheds).

- The large primary lagoon acts as a sludge storage site for many years. Hence, the piggery operator can focus on pig production and not worry about continual sludge removal and spreading operations.

- The provision of the second (and third) lagoon means that the primary treatment is always maintained at the same (and maximum) capacity. This reduces the likelihood of lagoon function disruption and subsequent odours.

- Recycling effluent reduces the volume of water to be irrigated. Hence, the piggery operator's effluent treatment responsibilities are further reduced.

- The treatment lagoon system requires little, if any, monitoring or maintenance to ensure adequate effluent treatment.

From an odour perspective, the main disadvantage of this system is that the large lagoon surface areas are significant sources of odour emission.

TABLE 8 – HERD DETAILS – 2000-SOW PIGGERY

Pig Type	No. of Pigs	Liveweight (t)	No. of 45 kg pigs	No. of SPU
Boars	102	20	451	162
Gilts	200	23	511	360
Dry Sows	1745	262	5818	2793
Lac. Sows	255	51	1131	636
Suckers	2474	9	195	247
Nursery	2355	24	522	1177
Porker	3087	69	1531	1543
Grower	6122	323	7168	6122
Finsher	3036	270	5991	4857
Pre-sale	756	80	1785	1209
TOTAL	20130	1130	25104	19019

TABLE 9 – MANURE PRODUCTION DETAILS – 2000-SOW PIGGERY

Pig Type	No. of Pigs	Total Solids (kg/day)	Volatile Solids (kg/day)	Total Manure (kg/day)
Boars	102	50	43	498
Gilts	200		With dry sows	
Dry Sows	1745	932	804	9320
Lac. Sows	255	370	263	3701
Suckers	2474	24	21	239
Nursery	2355	447	395	4466
Porker	3087	767	657	7674
Grower	6122	3163	2246	31633
Finsher	3036	1830	1299	16470
Pre-sale	756	477	339	4773
TOTAL	20130	8060	6066	80604

TABLE 10 – LAGOON DIMENSIONS FOR TYPICAL PIGGERIES

Lagoon Data	**200-sow unit**	**1000-sow unit**	**2000-sow unit**
	Primary Anaerobic Lagoon		
Capacity (ML)	13.5	67.0	134
Surface Area (m^2)	4096	16380	30976
Length at TWL (m)	64	128	176
VS Inflow (kg/day)	619	3108	6229
Lagoon Volume (m^3/pig)	6.7	6.7	6.7
VS reduction	85%	85%	85%
	Secondary Facultative Lagoon		
Capacity (ML)	1.2	5.9	11.8
Surface Area (m^2)	676	2304	4096
Length at TWL (m)	26	48	64
VS Inflow (kg/day)	93	466	934
VS Reduction	50%	50%	50%

Assumptions:

Internal batters	1 in 2.5
Freeboard	1 m
Depth	5 m (anaerobic)
	4 m (secondary)
Loading Rate	80 g VS/m^3/day (active capacity)
Sludge Provision	40% of internal capacity