On-farm evaluation of a pond-less piggery effluent treatment system using novel flocculation and filtration techniques

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Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

By

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Executive Summary

Eliminating anaerobic ponds from treatment systems may enhance water and nutrient recovery, and remove a major source of odour and carbon emissions from piggeries, an important step towards carbon-neutral pork. Recently, a novel de-watering and filtering system, the Z-Filter, was developed in Western Australia to treat waste streams in the mining, municipal waste and food processing industries. This project was undertaken to evaluate the use of a Z-Filter to treat piggery effluent and to assess the extent to which it could replace ponds in treatment systems.

A prototype Z-Filter was used to treat effluent from a single shed that housed pigs from 10 to 22 weeks of age. The Total Solids (TS) concentration of the effluent ranged from 1.3% to 2.4% during the trial. Average removal rates were 58% for TS, 73% for Volatile Solids (VS), 35% for total nitrogen and 50% for phosphorus. As expected, relatively low removal rates were achieved for ammonium N (14%), potassium (10%) and volatile fatty acids (16%). The average dry matter content (TS) of the separated solids was 22%. The solids were stackable with minimal seepage and could be transported easily.

Data from the trial were used to calculate the capital, operating and chemical costs of operating the Z-Filter which were then combined with output from PigBal 4 simulations of 200 and 2,000 sow farrow-to-finish piggeries to estimate the cost of operating a Z-Filter on a commercial scale. The estimated cost ranged from $50 to $132 per tonne of TS treated, depending on herd size and the TS concentration of the effluent. This equated to $0.04 to $0.12 per kg HSCW of finisher pigs sold. However, this did not take into account any revenue from by-products or potential savings in capital investment in other parts of the treatment system.

The PigBal 4 model was also used to quantify the nutrient content of the separated solids to which a fertiliser unit price was applied. The net value of these nutrients was conservatively estimated to be equivalent to about 20% of the operating cost of the Z-Filter.

Removal rates achieved by the Z-Filter were higher than most values reported for other types of separation systems in common use. However, the Z-Filter, in common with other mechanical systems, was unable to remove colloidal and aqueous phase solids from the filtrate, necessitating its further treatment in an anaerobic pond. Nevertheless, removal of 75% of the VS would decrease the required pond size by about 60%, resulting in considerable savings in capital expenditure which may offset that incurred by the Z-Filter.

This project was conducted with a prototype Z-Filter which performed reliably during the trial. The manufacturer is confident the commercial model of the Z-Filter, with regular maintenance, will have a lifespan of about 20 years. However, the long term performance of the commercial model of Z-Filter is yet to be determined. Day to day operation of the Z-Filter is relatively easy, requiring a medium degree of maintenance and supervision. Some degree of operator training is required. However, some producers may view the Z-Filter as too complex to operate and outside the competency of their staff. Unless considerable economic benefits can be demonstrated or environmental constraints prevent the use of traditional systems, producers may be reluctant to replace traditional pond systems with more sophisticated alternatives.

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1. Introduction

The most common effluent treatment systems in Australia are anaerobic ponds and direct application of manure to land, either as fresh effluent or after treatment in pond systems. Some form of pre-treatment is often used to remove coarse solids and to reduce the volume of anaerobic ponds required. However, as piggeries increase in size, there is often insufficient land available in the vicinity of the piggery for the sustainable reuse of the nutrients contained in the effluent. Therefore there is considerable interest in separation systems that produce stackable solids for storage or off-site disposal. Solid separation systems were extensively reviewed in 2002 by Watts et al (2002a) and evaluated by Watts et al (2002b). They reported Total Solids (TS) removal efficiencies (%TS) from 10-30%, depending on the initial TS content of the influent, for systems that did not require further de-watering post-treatment.

Recently a de-watering and filtering system, which is continuous and self-cleaning, has been developed by Z-Filter in Western Australia. According to the manufacturer, the primary component of Z-Filter is a fabric filter element referred as a sock, which follows a delta or approximately triangular path. The fabric sock is closed into a tubular form to contain the slurry to be processed, and opened to discharge the solids. The fabric is a porous material which is selected to best suit the dewatering application. As a de-watering system, the Z-Filter works as follows: the process starts at an elevated point on the machine with the Sock open. The slurry is fed in continuously and the Sock is formed into a closed tube around this material as the Sock advances. As the slurry is continuously fed into the downward inclined dewatering section, it “washes” over the Sock material, and much of the free water flows out through the Sock material almost immediately. This “washing” action also tends to prevent the fabric from being blinded (or clogged) by the suspended solids. From this point, the sock follows an upward serpentine path while being manipulated by a series of rollers that massage more liquid out of the thickened sludge. The Sock then passes through a series of pressure rollers, which provide the final de-watering stage. Once through these rollers, the Sock then moves horizontally at the top of the machine, and is opened above the discharge chute allowing the dewatered solids to drop onto the discharge conveyor. The Sock is then scraped down, washed, and progresses back to the position where it is filled again, and the cycle continues. The discharge conveyor can be any suitable conveyor, selected for the application and material being handled.

This study was undertaken to examine the effectiveness of a Z-Filter in treating piggery effluent.

2. Methodology

The evaluation of a prototype Z-Filter was conducted on a 35,000 standard pig unit (SPU) grow-out facility in Western Australia where pigs are housed in tunnel-ventilated buildings approximately 67 m long by 21 m wide, sub-divided lengthways into two 10.5 m wide compartments with separate air-spaces. The buildings are managed on an all-in, all-out basis, and typically each compartment houses around 1,200 pigs in two groups of 600 from approximately 10 to 22 weeks of age, with auto-sort technology used at various times during the grow-out period to draft out pigs of specific weights as required to meet market demand.

Each compartment has a floor comprised of concrete slats mounted over flushing channels flushed with re-cycled water from four 8,000 L tanks situated outside the end of the compartment. Effluent is flushed from the compartment in four separate lanes, each with its own flush tank, and flows into a central sump into which effluent from all buildings on site is discharged and then agitated before passing through a screw press. The liquid fraction from the screw press enters a series of treatment ponds and the solids are taken off site for composting. Re-cycled flush water is drawn from the final treatment pond. Very little fresh water enters the effluent stream other than spillage from drinkers, leaks, wash water, and rain entering the treatment ponds. Flushing frequency varies from two or three times per week when pigs first enter the buildings to daily towards the end of the grow-out period.

To evaluate the Z-Filter, a closed-loop system was created whereby effluent from each lane of a single compartment was collected separately, processed through the Z-Filter and the filtrate returned immediately to the original flush tank for re-use. This approach was necessary because the available equipment lacked the capacity to collect and homogenise effluent from an entire compartment prior to processing through the Z-Filter.

To create the closed loop system, a newly emptied and cleaned compartment in a building was modified to enable effluent from an individual flush lane to be contained in a transverse channel into which it drained from the flush channels. The effluent was then pumped into a 10,000 litre capacity tank adjacent to the Z-Filter in which a submersible pump (Ebara pump, model DVS - 2.2kW 3 phase; 18m head max.; 800l/min max) was used to constantly circulate the effluent. Following the addition of the coagulant solution, the circulating effluent was pumped through a static mixer where flocculant was added, after which it passed through a floc maturator that allowed flocculating particles to grow prior to flowing through the Z-Filter. Filtrate from the Z-filter was then pumped into an adjacent holding tank before being returned to the original flush tank for re-cycling as flush water the following day, thus creating the closed loop system. The solids removed by the Z-filter were conveyed to a nearby stack for removal off site. The entire process was repeated for the other three flush lanes.

Although the Z-Filter has potential to operate at 350-400 L/min, it was operated throughout the evaluation at a conservative influent flow rate of 200 L/min with the compression rollers operating at 2.5 Bar to accommodate the considerable variation in solids composition between flushes. The selected coagulant (Floquat FL 2949, SNF-Australia Ltd) was added to the collection tank in quantities of 1,000 and 800 ml (0.0125% or 0.010% concentration) on collection days 1 and 2, respectively. A solution containing 0.5% flocculant (FlopamTM, SNF-Australia) was infused into the effluent stream at 7.2 L/min for all flushes on collection day 1, and at 8.3, 9.8, 8.9 and 8.8 L/min into effluent from lanes 1,2,3,and 4, respectively, on collection day 2. Because of the variability in solids content of the effluent, the quantity of coagulant and flocculant added to each flush was determined by jar testing effluent samples taken from the collection tank.

For the economic evaluation, the PigBal 4 model was populated with typical diets and performance data to estimate annual production and composition of effluent from the compartment of the shed used for the evaluation. The model was also used to estimate effluent production from typical 200 and 2,000 sow farrow-to-finish herds with low and high flush effluent removal systems to calculate annual costs of solids removal using the Z-Filter system.

Measurements and Observations

About 8,000 L of effluent was collected after each flush. The collection tank took about 40 minutes to empty, during which time a 1 L sample was taken every 2-3 minutes from a port inserted into the pipeline through which effluent was pumped to the Z-Filter. On average 15 samples were taken for each flush. The samples were aggregated into a 20 L container which was then stirred continuously with a handheld paint mixer while a representative subsample (500 ml) was taken for chemical analysis. The sub-samples were placed in an insulated box before being stored on-farm at -20°C. Immediately after the effluent sample was taken, a sample of the filtrate was taken at the discharge point from the Z-Filter, and a sample of the solids taken from the machine's discharge conveyer. The filtrate and solids samples were aggregated in separate 20 L containers before mixing, sub-sampling and storage on-farm at -20°C within 30 minutes of collection.

Samples were packed on dry ice in insulated containers before air freighting to the Advanced Water Management Centre at the University of Queensland for chemical analysis.

Samples were collected weekly from 7 February to 28 March 2014. However, to keep analytical costs within budget, only samples taken on 7 and 21 February, 14, 21 and 28 March were analysed. For the first two sampling days, influent, filtrate and separated solids samples from each of the four flush-lanes were analysed (n=24), whereas on subsequent sampling days composite samples from the four daily flushes were submitted for analysis (n=9). The remaining samples are being stored at -20C for future use if required.

Analytical methods

Total solids (TS) and volatile solids (VS) were measured according to standard methods procedures 2540G (APHA, 2005). In brief, the samples were oven dried at 105oC for ~12 hours to determine the TS and subsequently burnt at 550°C in an air-limited supply furnace for 2 hours to determine the VS. Fixed solids (FS) were calculated by subtracting VS from TS.

Both total Chemical Oxygen Demand (tCOD) and soluble Chemical Oxygen Demand (sCOD) were determined following the closed colorimetric method 5220D of the standard methods for testing of water and wastewater (APHA, 1998) using a Merck COD Sprectroquant® test kit (range 500-10000 mg COD L-1) in combination with a Varian Cary 50 Conc UV-visible spectrophotometer (Varian Inc., USA).

Volatile fatty acids (VFA) that included acetic acid, propionic acid, iso-butyric acid, butyric acid, iso-valeric acid, valeric acid and hexanoic acid were analysed with an Agilent 7890A gas chromatograph (GC) equipped with an Agilent DB-FFAP column. The column was maintained at 140°C while the injector and FID detector were operated at 220 and 250°C, respectively with Ultra High Purity (UHP) Helium used as a carrier and makeover gas. All samples were mixed with formic acid prior to the analysis with all injections into the GC done in a splitless mode.

Phosphorus (dissolved reactive), nitrate, nitrite and ammonium nitrogen were analysed with an automated LACHAT 8000QC flow injection analyser (FIA) (Lachat instruments, Colorado, USA). Total Kjeldahl nitrogen (TKN) and phosphorous (TKP) were also analysed in accordance with APHA (1998). During all analyses, the total fractions were done by making appropriate dilutions to the raw samples while the soluble fractions were analysed by first centrifuging the samples at x 4000g for 10 minutes followed by filtration of the supernatant using 0.45 µm PES filters (Merck Millipore, Australia).

Elemental analysis for metals (including potassium) and phosphorus (as a cross-check to TKP) was done with Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) on samples that had been pre-digested with concentrated nitric acid.

3. Outcomes

The chemical composition of influent to the Z-Filter varied from lane to lane, with Lane 4 having higher levels of TS, VS and FS compared to the other three lanes (Figure 1). The composition of the influent also varied over the grow-out period with the TS content increasing as the grow-out period progressed (Figure 2).

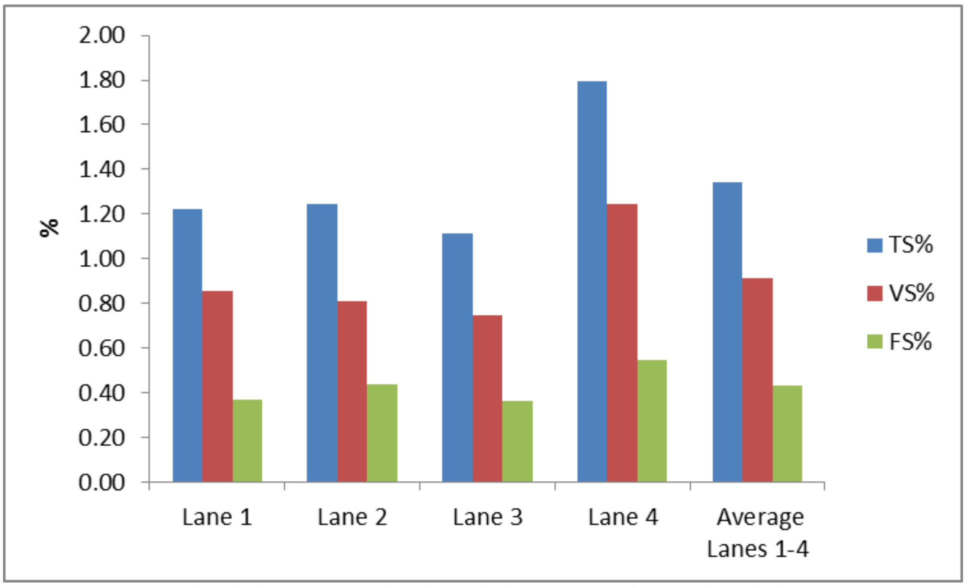


Figure 1 - Total solids (TS), Volatile Solids (VS) and Fixed Solids (FS) concentration of influent from the four flush lanes (average of 1st and 2nd sampling days).

The composition of the influent was affected by the number of times it was re-cycled through the shed, which varied from twice prior to the first sampling day and eleven times prior to the last sampling day. However, this effect could not be reliably quantified as it was confounded by changes in the quantity and composition of manure produced during the grow-out period.

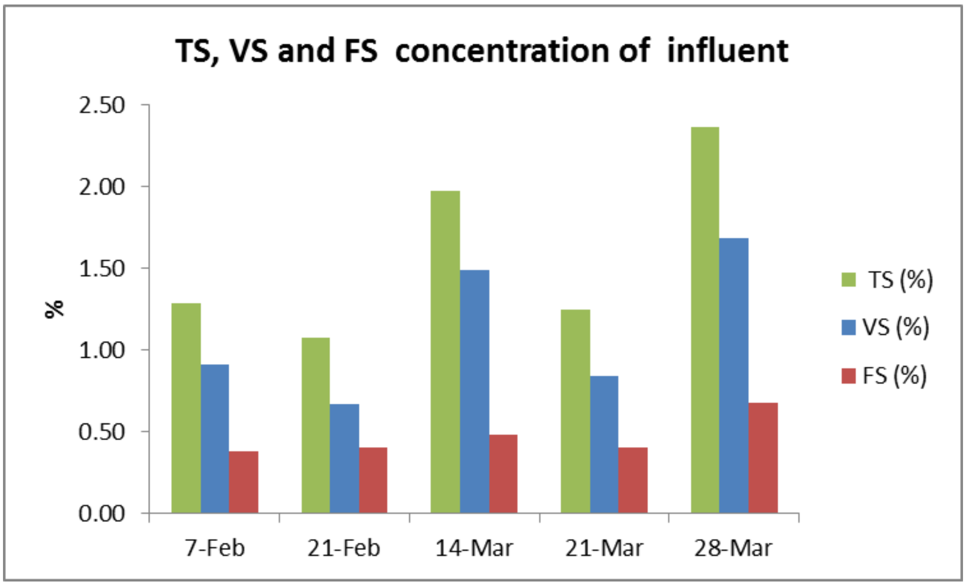


Figure 2 - Total solids (TS), Volatile Solids (VS) and Fixed Solids (FS) concentration of influent samples taken on each sampling day.

Results shown in Figure 2 for samples taken on 7 and 21 February are the average of the individual samples taken from the four flush lanes, whereas on the other sample days a composite sample aggregated from the four flush lanes was used for analysis.

The average chemical composition of influent and filtrate from the Z-Filter and percentage removal rates are shown in Table 1.

Table 1 - Chemical composition of influent and Z-Filter filtrate

Parameter	Influent	Filtrate	% Removal
TS (%)	1.59	0.66	58.3
VS (%)	1.12	0.31	72.8
FS (%)	0.47	0.35	25.0
VS/TS	0.69	0.45	-
COD (mg/L)	18,269	6,575	60.1
SCVFA (mg/L)	3,124	2,627	16.0
TKN (mg/L)	1,370	897	35.1
NH4- N (mg/L)	851	738	13.7
P (mg/L)	223	67	65.1
PO_4- P (mg/L)	63.8	33.0	49.47
K (mg/L)	936	843	10.1

Over half of the TS (58%), nearly three quarters of the VS (73%) were removed by the Z-Filter. A third (35%) of the TKN, two thirds of the P and just under half (50%) of the phosphate content were removed. As expected, removal rates for soluble components such as ammonium N and K were low at 14% and 10%, respectively.

The increase in TS concentration of the influent is shown graphically in Figure 3, together with removal efficiencies for key nutrients. It can be seen that removal efficiencies remained relatively constant for influent TS concentrations ranging from 1.3% to 2.4%.

The chemical composition of solids removed by the Z-Filter is shown in Table 2. Nutrient concentrations, particularly N, P, and K increased over time. The solids at 21.9% dry matter (TS) were stackable with only minimal moisture seepage. It is also clear from Table 2 that the Z-filter mainly removes organic solids, as seen by the much higher VS to TS ratio of the solids in comparison to the influent. It is noteworthy that a large proportion of the phosphorus in the influent (Table 1) and solids (Table 2) was phosphate, which together indicates that the flush effluent contained a significant amount of phosphate-based mineral solids.

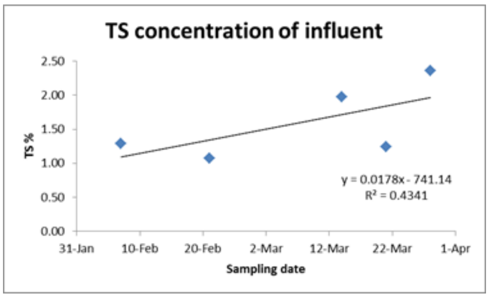
Table 2 - Average Composition of solids removed by the Z-Filter

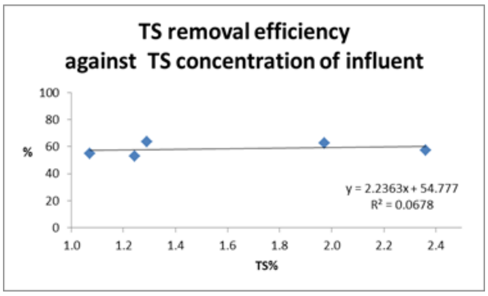
Parameter	Separated solids
Total solids (%)	21.9
Volatile Solids (%)	19.1
Fixed Solids (%)	2.87
SCVFA (mg/kg wet solids)	6,934
TKN (mg/kg wet solids)	4,005
NH4-N (mg/kg wet solids)	1,560
P (mg/kg wet solids)	2,224
PO_4-P (mg/kg wet solids)	1,164
K (mg/kg wet solids)	1,073

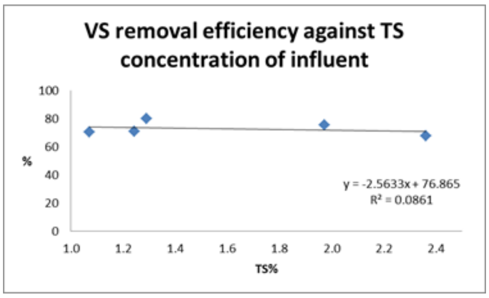
The range in Total Solids (TS) concentration of the influent found in this study was typical of reported values for daily flush systems in Australia. In contrast to the almost universal practice of using water taken from the last of a series of treatment ponds, flush water in this study was re-cycled filtrate obtained directly from the Z-Filter without further processing. The filtrate was re-used on two, four, three, three and eleven consecutive days prior to sampling on collection days 1, 2, 3, 4 and 5, respectively. This may have significantly altered its composition relative to flush water extracted after treatment in a series of ponds prior to re-use.

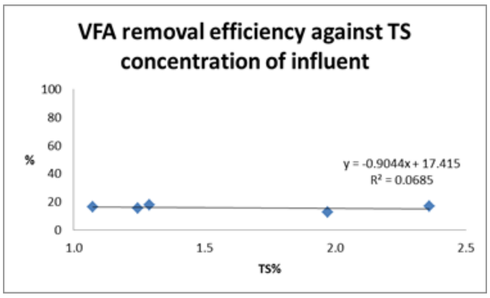
Sampling of effluent was complicated by the all-in, all-out management of the building. The selected compartment was filled with about 1,270 10 week old pigs on 1 February 2014 where they remained as a group until 28 March 2014 when the first tranche of pigs was marketed. The amount of excrement increased daily as the pigs grew at about 800 g/d during this period. Further, the TS concentration of four flush lanes varied due to changing resting and voiding behaviours of the pigs. Initially, pigs tended to lie close to the side walls and excrete in the more central areas of the compartment, resulting in a higher concentration of excrement in the middle two flush lanes. This pattern appeared to change over time with excretory behaviour concentrated over flush lane 4 in the vicinity of the interior wall of the compartment. Thus the composition of the influent to the Z-Filter varied between flush channels on the same day and also with time as the grow-out period progressed.

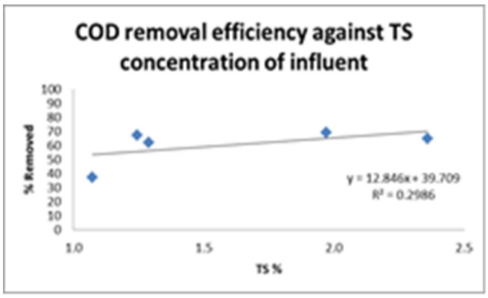
The constant variation in TS concentration of the influent necessitated assessing the coagulant and polymer dose rate for each flush. This was achieved successfully as evidenced by the relatively constant solids and nutrient removal rates measured for influent when TS concentrations ranged from 1.3% to 2.4% (Figure 3).

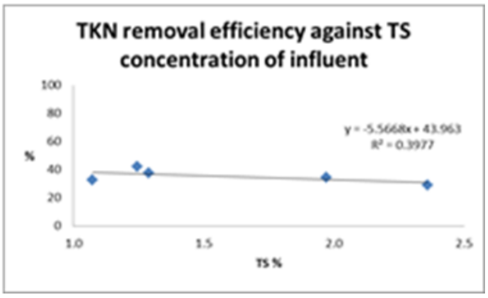












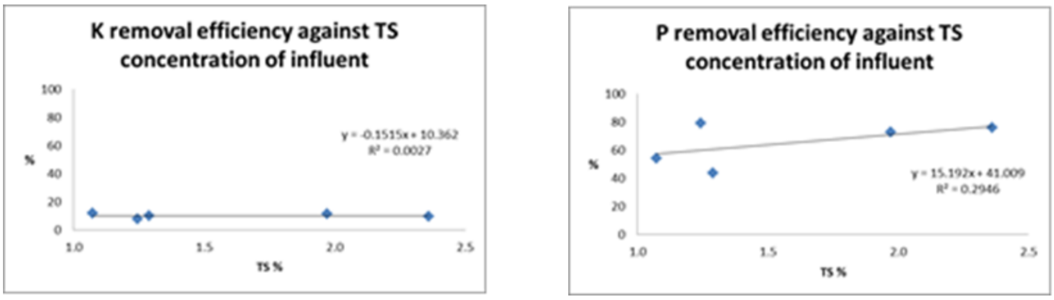


Figure 3 - Percentage removal efficiency(y axis) in relation to percentage Total Solids (TS) concentration of influent (x axis).

The TS removal efficiency is at the upper end of reported values for other commercially available systems in Australia. A review of separation systems (Watts et al, 2002b) reported TS removal efficiencies from 20% for static screens, screw presses and belt presses, 50% for Tangential Flow Separators, and 70% for Dissolved Air Flotation Systems. Further, a study by Shulz & Lim (1994) found that about 30% of TS in piggery effluent were contained as colloidal and aqueous phase solids which were unlikely to be removed by mechanical means alone. Shulz & Lim (1994) also reported that about 40% of the COD was contained in colloidal and aqueous phase solids, suggesting that TS separation efficiencies greater than 70% may be difficult to achieve without additional processing of the filtrate.

4. Application of research

An Excel spreadsheet model was created to calculate the cost of chemicals used per tonne of TS treated and per ML of influent treated. The output from the model is shown in Table 3. It should be noted that the chemicals were purchased in small quantities for the trial, and that the price would be considerably lower if the chemicals were purchased in bulk.

Table 3 - Estimated cost of chemicals used by the Z-Filter

Item	Units	Trial data	PigBal Model High Volume Flushing 1% TS	PigBal Model Low Volume Flushing 3% TS
Approx. volume of influent per flush	L	8,000	8,000	8,000
Density of influent	g.ml^{-1}	1.023	1.023	1.023
Average TS content of influent treated	%	1.37	1.00	3.00
TS per tank of influent	kg	112.12	81.84	245.52
Influent feed rate into Z-Filter	L.min^{-1}	200	350	350
TS feed rate kg per minute	kg.min^{-1}	2.80	3.58	10.74
TS feed rate tonne per hour	t.h^{-1}	0.168	0.215	0.644
Av. vol. coag added to collection tank	ml	1,115	1,115	1,115
Assumed density of coag	g.ml^{-1}	1.14	1.14	1.14
Weight of coag added to collection tank	kg	1.27	1.27	1.27
Number of tanks to which coag added		1	1	1
Price of coag	$/kg	$ 2.80	$ 2.80	$ 2.80
Cost of coag per kg TS treated	$/kg	$ 0.03	$ 0.04	$ 0.01
Cost of coag per tonne TS treated	$	$ 31.74	$ 43.49	$ 14.50
Vol. of coag per L of influent treated	ml.L^{-1}	0.14	0.14	0.14
Weight of coag per L of influent treated	g.L^{-1}	0.16	0.16	0.16
Weight of coag used per hour	kg.h^{-1}	1.91	3.34	3.34
Cost of coag per L of influent treat	$	$ 0.0004	$ 0.0004	$ 0.0004
Cost of coag per ML of influent treat	$	$ 444.89	$ 444.89	$ 444.89
Polymer concentration	%	0.5	0.5	0.5
Assumed density of polymer		1.04	1.04	1.04
Price of polymer	$/kg	$ 3.65	$ 3.65	$ 3.65
Polymer solution infusion rate	L.min^{-1}	7.72	7.72	13.5
Vol. of polymer infused per minute	L.min^{-1}	0.039	0.039	0.068
Wt. of polymer infused per minute	kg.min^{-1}	0.040	0.040	0.070
Wt. of polymer infused per hour	kg.h^{-1}	2.409	2.409	4.212
Wt. of polymer per kg of TS treated	kg.kg^{-1}	0.014	0.011	0.007
Wt. of polymer per tonne of TS treated	kg.t^{-1}	14.322	11.212	6.535
Cost of polymer per tonne TS treated	$	$ 52.27	$ 40.92	$ 23.85
Vol. of polymer per L of influent treated	L	0.000193	0.000110	0.000193
Weight of polymer per L of influent treated	kg	0.000201	0.000115	0.000201
Cost of polymer per L of influent treat	$	0.000733	0.000419	0.000732
Cost of polymer per ML of influent treat	$	$ 732.63	$ 418.64	$ 732.09
Summary				
Chemical cost per tonne TS treated	$/t	$ 84.02	$ 84.41	$ 38.35
Chemical cost per ML influent treated	$/ML	$ 1,177.51	$ 863.53	$ 1,176.97

To obtain the output shown in Table 3, the spreadsheet was populated with average values for parameters that varied with each flush and the price of chemicals (entered into yellow cells of the spreadsheet). A series of calculations was then performed to estimate the cost of chemicals used during the evaluation. A second spreadsheet was populated with output from the PigBal 4 model that simulated pig throughput and effluent production for the grow-out shed used in the evaluation and for typical low and high flush volume 200 and 2,000 sow farrow-to-finish herds (Table 4). Also included were chemical costs derived from the previous spreadsheet (shown in Table 3), and annual capital, running and maintenance costs supplied by Z-Filter Pty Ltd. This approach was used by Watts et al (2002) to evaluate 14 separation systems in a series of case studies. However, they used an earlier version of Pigbal to simulate output for the two production systems modelled, which may have resulted in the use of different estimates of TS concentration of the effluent, feed wastage, drinking and hosing water, water wastage and flushing volumes assumed in their case studies.

Modelling conducted for this project indicates the cost of capital and operating costs of using the Z-filter to separate solids ranged from $50 to $132 per tonne of TS treated, or from $0.04 to $0.12 per kilogram of dressed finisher weight sold per year, depending on the size of the operation and the volume of flush water used. Substantial economies of scale were identified using this method of evaluation. However, there may be considerably opportunities to reduce chemical costs further through bulk purchase, which is important because Table 4 shows that chemical costs appear to dominate the overall economics.

Table 4 - Estimated capital and operating costs for the Z-Filter for typical low and high flush 200 and 2,000 sow farrow-to-finish herds.

	Units	Assumptions	Shed 11B annual effluent output (from PigBal 4)	200 sow farrow to finish high-flush (from PigBal 4)	200 sow farrow to finish low-flush (from PigBal 4)	2,000 sow farrow to finish high-flush (from PigBal 4)	2,000 sow farrow to finish low-flush (from PigBal 4)
PigBal Output							
No. of pigs per batch	grower/finishers		1,270	2,125	2,125	21,229	21,229
SPU equivalent per batch	SPU		1,867	2,137	2,137	21,338	21,338
Annual throughput	grower/finishers/yr		4,915	4,448	4,448	44,470	44,470
Dressed weight of finisher sold per year	kg		399,698	343,093	343,093	3,430,927	3,430,927
Effluent discharged from shed	L/d		39,708	83,573	27,858	834,736	278,245
Total effluent production	ML/yr		14.49	30.50	10.17	304.68	101.56
Measured output							
Density of effluent			1.023	1.023	1.023	1.023	1.023
Solids content of effluent	% TS		1.37	1.00	3.00	1.00	3.00
TS discharged from sheds	$kg.day^{-1}$		557	855	855	8,539	8,539
TS produced	t/yr		203.13	312.06	312.06	3,116.86	3,116.86
Z-Filter flow rate	L/min		200	350	350	350	350
Required Z-Filter operating time	hr/d		3.31	3.98	1.33	39.75	13.25
Numer of machines required assuming run time of 8 hr per day			1	1	1	5	2
Annual run time	hr/yr		1,207.79	1,452.58	484.20	14,508.51	4,836.16
Solids removal	(%)		59	59	59	59	59
Solids removed per year	t		119.6	183.7	183.7	1,835.21	1,835.21
Nominal cost of machine	$	$ 120,000.00					
Total capital cost			$ 120,000.00	$ 120,000.00	$ 120,000.00	$ 600,000.00	$ 240,000.00
Capital costs	$/ML treated/yr		$ 8,279.62	$ 3,933.89	$ 11,801.53	$ 1,969.29	$ 2,363.15
	$/t TS removed per year		$ 1,003.34	$ 653.10	$ 653.09	$ 326.94	$ 130.78
Interest rate	%	8.0					
Working life of machine	yr	20.0					
Annual capital costs			$ 6,480.00	$ 6,480.00	$ 6,480.00	$ 32,400.00	$ 12,960.00
Maintenance costs	$/hr	2.76					
Annual maintenance cost			3,333.49	4,009.12	1,336.39	40,043.48	13,347.81
Annual labour cost	$	$ 4,192.00	4,192.00	4,192.00	4,192.00	20,960.00	8,384.00
Annual chemical cost*			$ 17,066.19	$ 26,341.23	$ 11,967.64	$ 263,099.02	$ 119,532.47
Total annual cost			$ 31,071.68	$ 41,022.35	$ 23,976.03	$ 356,502.49	$ 154,224.28
Cost per kg dressed weight of finishers sold	**$/kg**		**$ 0.08**	**$ 0.12**	**$ 0.07**	**$ 0.10**	**$ 0.04**
Cost per ML treated	$/ML		**$ 2,143.85**	**$ 1,344.81**	**$ 2,357.95**	**$ 1,170.09**	**$ 1,518.56**
Cost per tonne TS treated	**$/t**		**$ 152.97**	**$ 131.46**	**$ 76.83**	**$ 114.38**	**$ 49.48**
Cost per tonne TS removed	**$/t**		**$ 259.79**	**$ 223.26**	**$ 130.49**	**$ 194.26**	**$ 84.04**

*Calculated using the chemical cost per tonne TS treated.

The cost per ML of effluent varied markedly depending on the volume of flush water used, an artefact of simultaneously varying TS concentration and the volume of the effluent in the model. The volume of effluent to be treated impacts greatly on the number of machines required as there is a limit on flow rate through the Z-Filter. The prototype Z-Filter was run at 200 L/min during the trial but the next generation of production models are expected to run conservatively at 350 L/min with a maximum of 400 L/min. A flow rate of 350 L/min was assumed in Tables 4 and 5.

In contrast, total TS production remains constant regardless of the volume of flush water used. The quantity of polymer used is dependent on the TS concentration of the influent. Therefore the cost per tonne of TS treated more accurately reflects the estimated cost of running the Z-Filter. However, expressing the cost per tonne of TS removed also takes into account the removal efficiency of the Z-Filter. On this basis, estimated costs $161 per tonne of TS removed for a 2,000 sow low-flush herd to $223 for a 200 sow high-flush herd.

To put these costs into perspective, the operating costs per tonne of TS removed for 14 separation systems reported by Watts et al (2002), adjusted for the 38.7% inflation that occurred from 2001-13 (http://www.rba.gov.au/calculator/), are shown in Table 5. However, any comparison of this nature should be viewed with extreme caution because of possible differences in how costs were calculated and assumptions used by Watts et al (2000b) compared to this study. For example, Watts et al (2002b) did not include the annual capital cost and depreciation in their costings. Thus these items have not been included in the operating costs for the Z-Filter shown in Table 5. Watts et al also cautioned that some of the data used in their estimates was regarded as preliminary and that sound data on solids removal was often lacking, as was continuous operating data for several of the systems. Further, the cost of some items may have risen at a greater rate than the consumer price index over the 12 year interval between the two studies. Notwithstanding these limitations, the comparison shows that the operating costs of the Z-Filter are competitive with other more sophisticated separation systems.

Table 5 - Solids removal efficiency and operating cost ($/t of solids removed) of separation systems (from Watts et al, 2000b).

	Solids removal efficiency (% TS)		200 sow high flush	200 sow low flush	2,000 sow high flush	2,000 sow low flush
	1.2% TS (high flush)	3.1% TS (low flush)				
Sedimentation Basin	50	50	$ 139	$ 148	$ 49	$ 51
SEPS	60	60	$ 15	$ 10	$ 8	$ 6
Static Rundown Screen	20	20	$ 96	$ 83	$ 39	$ 32
Vibrating screen	10	20	$ 333	$ 119	$ 96	$ 33
Rotating Screen	10	15	$ 387	$ 160	$ 89	$ 55
Baleen Filter screen	30	30	$ 112	$ 143	$ 29	$ 29
Screw Press Separators	10	20	$ 200	$ 76	$ 108	$ 35
Belt Presses[a]	10	20	$ 470	$ 153	$ 172	$ 62
Hydrocyclones	25	25	$ 80	$ 55	$ 29	$ 18
Centrifuge/Decanters	20	30	$ 451	$ 270	$ 67	$ 43
Dissolved Air Flotation	70	70	$ 122	$ 119	$ 44	$ 37
Tangential Flow Separators	50	50	$ 361	$ 361	$ 108	$ 85
Dry scraping Systems	100	100	$ 15	$ 14	$ 10	$ 10
Z-Filter[b]	59	59	$ 92	$ 54	$ 87	$ 44
Z-Filter[c]	59	59	$ 81	$ 51	$ 75	$ 40

[a] does not include cost of polymer use.

[b] retail price for chemicals

[c] 20% discount price for chemicals

One of the attractions of using solid separators is the potential offered for recovering the fertiliser value of the solids produced on an annual basis. PigBal 4 was used to estimate the nutrients contained in the filtrate and the separated solids using removal rates determined in the trial. Using fertiliser prices of $1.60, $4.50 and $1.50 per unit of N, P and K, respectively, the estimated notional annual fertiliser values were $29,846 for the 200 sow unit and $298,038 for the 2,000 sow unit (Table 6). In practice it is extremely difficult to realise the full value of the nutrients produced. Recent studies show that spent bedding from deep litter systems realises about 40% of its notional fertiliser value by the time it is applied. Conservatively, assuming that 25% of the fertiliser value of Z-Filter solids can be realised, the net value of the solids produced is about $7,500 for the 200 sow herd and $74,000 per year for the 2,000 sow herd which represents about 30% and 45%, respectively, of the hypothetical annual cost of operating Z-filters on these units

The methane emission potential was not measured directly during this project, but using the same calculation method as the PigGas model, it is estimated that the Z-Filter solids could produce about 155 kg/d methane (190 m^3/d of biogas at 70% methane) and 1545 kg/d methane (1,900 m^3/d of biogas at 70% methane) and the filtrate 54 kg/d methane and 543 methane kg/d for the 200 and 2,000 sow herds respectively. Thus, in some situations, possibly there may be potential to use the Z-filter solids in some form of biogas digester and the filtrate in a covered anaerobic pond, although further consideration of these possibilities is outside the scope of this project.

It is simplistic to appraise the Z-Filter system on the basis of capital and operating costs alone without regard to its impact on the entire effluent management system. For example, the PigBal 4 model indicates the required anaerobic pond capacity for a 2,000 sow unit near Albury, NSW, with a loading rate of 0.100 kg VS $m^{-3}.d^{-1}$ and a 20 year de-sludging interval, was 272,214 m^3 without any type of solid separation, and could be reduced to 98,471 m^3 by installing a Z-Filter system with a 75% VS removal rate. This size reduction of 64% represents a saving of $521,229 in pond costs alone (assuming a construction cost of $3 / m^3), which would offset the capital cost of a Z-Filter system. Other possible benefits include a smaller surface footprint, reduced odour and GHG emissions, and the potential fertiliser value of separated solids.

PigBal4.v4 Output		Shed 11B trial data					Hypothetical 200 sow F-F low flush					Hypothetical 2,000 Sow F-F low flush				
Parameter	**Units**	**TS**	**VS**	**N**	**P**	**K**	**TS**	**VS**	**N**	**P**	**K**	**TS**	**VS**	**N**	**P**	**K**
Effluent discharged from sheds	kg. day-1	637	536	50	12	12	836	701	65	16	15	8,347	7,006	651	156	154
Typical pre-treatment removal rates	%	32%	37%	37%	41%	8%	32%	37%	37%	41%	8%	32%	37%	37%	41%	8%
Known pre-treatment removal rates	%	**59%**	**74%**	**35%**	**61%**	**11%**	**59%**	**74%**	**35%**	**61%**	**11%**	**59%**	**74%**	**35%**	**61%**	**11%**
Adopted pre-treatment removal rates	%	59%	74%	35%	61%	11%	59%	74%	35%	61%	11%	59%	74%	35%	61%	11%
Separated solids	kg. day-1	376	397	18	7	1	493	519	23	10	2	4,925	5,185	228	95	17
	t. yr-1	137	145	6	3	0	180	189	8	3	1	1,798	1,892	83	35	6
Effluent entering primary pond	kg. day-1	261	139	33	5	11	343	182	42	6	14	3,422	1,822	423	61	137
	t. yr-1	95	51	12	2	4	125	67	15	2	5	1,249	665	154	22	50
Assumed value per unit (per kg of element)	$/unit			$ 1.60	$ 4.50	$ 1.50			$ 1.60	$ 4.50	$ 1.50			$ 1.60	$ 4.50	$ 1.50
Notional fertiliser value of influent	$			$ 29,311.09	$ 19,338.81	$ 6,563.35			$ 38,042.05	$ 25,581.64	$ 8,423.70			$ 379,923.16	$ 255,429.39	$ 84,114.94
Notional fertiliser value of entering pond	$			$ 19,052.21	$ 7,542.13	$ 5,841.38			$ 24,727.33	$ 9,976.84	$ 7,497.10			$ 246,950.05	$ 99,617.46	$ 74,862.30
Notional fertiliser value of separated solids	$			$ 10,258.88	$ 11,796.67	$ 721.97			$ 13,314.72	$ 15,604.80	$ 926.61			$ 132,973.10	$ 155,811.93	$ 9,252.64
Total notional fertiliser value of separated solids	$			22,777.52					29,846.12					298,037.68		
Estimated methane emissions	(From PigGas) = VS (kg/d) * 0.45 (m^3 methane/kg VS) * methane conversion factor * 0.662 (kg/m^3 methane)															
Estimated methane emission potential fron	kg/d		118.1896					154.6231					1544.516			
Estimated methane emissions from filtrate	kg/d		41.52608					54.32704					542.6678			

Table 6 - Estimated fertiliser value of Z-Filter separated solids and biogas potential of Z-Filter filtrate and solids.

Commercialization/Adoption Strategies

Potential benefits to cost of production

The contribution of effluent management to the cost of production is difficult to quantify, and the cost per kg HSCW sold is seldom quoted. From data extrapolated from the FSA Report Number 54921/1 July 2000 suggests the 2014 capital and operating costs of a simple two pond system amount to \$0.08 to \$0.10 per kg HSCW. There is little opportunity to reduce this cost other than by offsetting the cost with revenue generated by biogas capture and nutrient re-use. However, the latter invariably require additional capital expenditure and site specific benefit: cost analysis is required before a rational decision can be made. However, in some situations, the use of a Z-Filter system may enable the net cost of effluent management to be reduced by offsetting the capital investment in the treatment system with revenue from recovered solids and biogas utilisation.

Ease of adoption by producers

The Z-Filter is one of several solid separation systems available to producers. This project has provided performance data that will enable informed decisions to be made about its use. The information generated by this project can be used to design integrated effluent management systems that may include a solid separation system such as the Z-Filter, biogas capture, and nutrient re-use.

The Z-Filter in this trial was evaluated under very difficult conditions caused by the great variation in TS concentration of the influent. Under more usual commercial conditions where shed effluent is aggregated in a tank or a sump before the separator, less variation in TS variation is likely to occur. This will reduce the need for constant adjustment to coagulant and polymer dose rates. It is also anticipated that the commercial model of the Z-Filter will require less maintenance and supervision than the prototype used in this trial. In terms of ease of use, operation of the Z-filter is probably on a par with other technologies such as liquid feeding systems.

5. Conclusion

The Z-Filter removed about 58% of the TS, 73% of VS, 60% of COD, 35% of N, 65% of P and 10% of K present in the influent. Removal rates were relatively constant for influent TS concentrations from 1.3% to 2.4% experienced during the trial. As expected, the filtrate contained large quantities of VFA and other soluble nutrients that would require further treatment in an anaerobic pond. The relatively high VS removal rate would reduce the volume of such a pond, if sized on VS loading rate, by about two thirds compared to that required without a Z-Filter system in place. Separated solids contained 22% TS (dry matter), 19.15 VS and 2.9% FS. The solids also contained 6,934, 4,005, 2,224 and 1,073 $mg.kg^{-1}$ wet solids of VFA, TKN, P and K, respectively. The cost of chemicals (coagulant and polymer) was estimated to be \$84 per tonne TS treated. However this was based on purchasing the chemicals in small quantities for the trial and it is anticipated that the price would be considerably lower if the chemicals were purchased in bulk quantities.

The PigBal 4 model was used to simulate production and effluent output from a 200 and a 2,000 sow farrow to finish piggery to enable the cost of capital and operating costs of operating the Z-Filter on a commercial scale to be estimated. Estimated costs ranged from \$162 to \$208 per tonne of TS removed from the influent, or from \$0.08 to \$0.13 per kg HSCW of growers sold, depending on the TS concentration and size of the operation. However, these economics were dominated by chemical costs to operate the system and, with bulk purchase of chemicals, may be considerably reduced. Also, the costs do not take into account savings in other infrastructure costs (e.g. smaller ponds), the nutrient value of the separated solids which may or may not be realised. The value of an individual component such as a Z-Filter in an effluent management system requires a system to be examined in its entirety which is beyond the scope of this project. However, it appears that a commercial version of the Z-Filter may be a cost-effective means of minimising the environmental impact of effluent management and maximising returns from effluent by-products.

6. Limitations/Risks

This project was conducted with a prototype Z-Filter which performed reliably during the trial. The manufacturer is confident the commercial model of the Z-Filter, with regular the maintenance, will have a lifespan of about 20 years. However, the long term performance of the commercial model of Z-Filter is yet to be determined. Day to day operation of the Z-Filter is relatively easy, requiring a medium degree of maintenance and supervision. Some degree of operator training is required. However, some producers may view the Z-Filter too complex to operate and outside the competency of their staff. Unless considerable economic benefits can be demonstrated or environmental constraints prevent the use of traditional systems, producers may be reluctant to replace simple ‘install and forget’ pond systems with more sophisticated alternatives.

7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

Producers are increasingly regarding piggery manure as a resource rather than an unavoidable cost of doing business. Recently, opportunities for biogas collection and utilisation have been identified and are rapidly being adopted by producers. In contrast, although the fertiliser value of pig manure in all its forms has long been recognised, it has not fully exploited because of the difficulties in cost-effectively extracting, storing and utilising the nutrients it contains. Several options now exist for biogas production and for solids separation and nutrient recovery. There is a need for a decision process to determine the optimal combination of solids separation, biogas generation and desludging and liquid treatment systems. Therefore it is recommended that:

- Case studies should be conducted and/or economic models developed to determine on a site-specific basis the most cost-effective combinations of the many options now available for effluent removal, biogas production, solids separation and liquid treatment systems.
- The decision-making models should incorporate capital and operating costs, water and energy use and cost, and the value of by-products produced. The model(s) should also be able to estimate capital requirement, return on capital, and cost of the integrated system per kg HSCW.

8. References

References for analytical methods:

APHA (American Public Health Association), American Water Works Association, Water Pollution Control Federation, 1998.

Standard Methods for the Examination of Water and Wastewater. 20th ed., American Public Health Association, Washington, DC.

Other references:

Schulz T and Lim BPL (1994). *The significance of solids on the composition of piggery wastewaters – Development of a database on odour emission rates in various piggery operations*. Report PD 1994-7. University of New South Wales, Sydney.

Watts PJ, Tucker RW, Pittaway PA, and McGahan EJ (2002a). *Low cost alternatives for reducing Odour Generation*. Milestone no.5 of Project 1629, Part A Report, Australian Pork limited, Canberra, Australia, April 2002.

Watts PJ, Tucker RW, Pittaway PA, McGahan EJ, Kruger IR and Lott SC (2002b). *Low cost alternatives for reducing Odour Generation*. Milestone no.5 of Project 1629, Part B Report, Australian Pork limited, Canberra, Australia, April 2002.

10. Appendix - Acknowledgements

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