DEVELOPING A COMPOSITE STORAGE TANK; FOR WATER AND WASTE TREATMENT

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ABSTRACT

KlipTank NZ plastic tank systems were designed to be easy to install, cost effective and earthquake resilient to meet a niche need for liquid storage in the food industry.

The tank system was made public during the initial period of improved dairy shed effluent (DSE) management, via storage, was being implemented within the dairy sector. DSE storage was a market for KlipTank that has resulted in the development of additional technologies, enabling the tank to form the basis of a range of treatment systems.

This paper outlines the development of a DSE treatment method by aeration and details benefits this has on the discharge environment. How keeping it simple can reduce capital expenditure and how developing one treatment option leads to other options including trickle aeration, dissolved air flocculation (DAF) and anaerobic digestion reactors.

The paper also describes savings gained from recent municipal applications of the plastic tank system and possible applications of technology in smaller Waste Wastewater Treatment Plants.

KEYWORDS

Tank storage

Dairy effluent

Aeration, AD, DAF

1 INTRODUCTION

Liquids storage at large-scale or industrial volumes can be in a variety of container systems, but generally limited to tanks or ponds. Tanks are commonly constructed of metals or concrete and like ponds can utilise plastic liners. Plastic and carbon fiber tanks have been traditionally limited to approximately 45 m^3 of liquid volume. Until recently large volume composite tanks, $100m^3$ or more, were not readily available (Boyle and Mahmood, 2009).

To ease manufacture many metal and concrete tanks are constructed in segments fixed together on site, this concept was the genesis for the development of KlipTanks composite tank system capable of storing liquid volumes to $4000m^3$.

Dairy shed effluent (DSE) consists of dairy excreta collected from the dairy milking shed and associated yards, process and wash down water, clean in place (CIP) water and detergents; many dairy farms also have some storm water inputs from yards and roofs.

DSE is highly variable in its make up with total solids (TS) reported in the ranges of 0.5 – 15 g L^{-1} (Longhurst et al., 2000, Taiganides, 1977).

Volatile solids (VS) generally falls within 80 – 86 % of TS the remainder being ash, as fixed solids, (Zhang et al., 2003, ASAE, 2005, Wright, 2005).

The fixed solids (FS) constitute the residual inorganic compounds (N, P, K, Ca, Cu, Zn, Fe etc.) in a suspended or dissolved state

The content of total suspended solids (SS) ranges from 62% to 83% of TS (Wright, 2005, Zhang et al., 2003).

The BOD^5 of animal effluents has some differences when compared to that of sewage, as BOD^5 of sewage represents 68% to 80% of the ultimate BOD, whereas that of animal effluents is only 16% to 26% (a dairy cows rumen having already processed the feedstock, consequently the effluent contains a higher proportion of slowly degradable organic matter, greater than 5). Typically, dairy effluent, unless substantially diluted, has a BOD^5 of the order of 2500– 4000 mg L^{-1}. The contribution from CIP wash down cannot be ignored, raw milk has a BOD^5 of 100 000 mg L^{-1} with the potential to be a powerful pollutant if inappropriately managed. (Australia, 2014, Metcalf & Eddy et al., 2003).

Generally DSE is treated via application to land with a national trend for storage of DSE during periods where discharge is not allowed under the appropriate regional plan. Managing DSE through storage has been predominantly focused on reducing harm to the receiving environment (Dairynz, 2013, RMA, 1991), with most parameters designed around controlling runoff, leaching and ponding; all regional plans, such as Waikato regional Council (WRC, 2016), include rules covering nitrogen loads (as total nitrogen) with some Regional Councils also manage specific environmental effects such as run-off into lakes (EBOP, 2016).

DSE storage systems can be in excess of 5000 m^3 with effluent stored for months before discharge to land. Many DSE storage systems have rudimentary or no mixing systems or monitoring, consequently sedimentation, hardpan formation and septic conditions can eventuate (Buchanan, 2010, Perterkin, 2013).

Land based DSE disposal could be improved by adding treatment technologies to storage systems (Bolan et al., 2009). Treatment systems can include anaerobic digestion reactors, aeration tanks, solids removal, such as dissolved air flocculation (DAF) and pre storage solid separation systems (Lords, 2013). European and North American dairy farms consider AD a first choice treatment option, this is because animals are inside most of the time enabling collection of a majority of the animal waste, energy costs and subsidies have also added weight to using anaerobic digestion (Lords, 2013, Bywater, 2011, Yeatman, 2007, Bailey, 2013). The effluent inputs from NZ farms are much lower than for Northern Hemisphere farms with resultant lower biogas potential and therefore less payback opportunity against capital inputs and treatment benefits (Milet et al., 2015, Dairynz, 2015).

KlipTanks' philosophy was to design a simple tank storage system that was fast to install and could be easily moved or removed. The nature of composites enables a life cycle on par with concrete and steel; with high earthquake resilience and a lower capital cost. There is a range of liners available for water and bulk liquid storage; roofs or covers designed, finalising this new tank storage system. KlipTanks were quickly adapted to dairy shed effluent storage but KlipTank identified that some treatment was needed as part of the DSE storage system.

To date there has been little uptake of AD as a treatment option in NZ dairy farms. Aerated treatment is well understood in municipal and industrial waste treatment; could an aerated treatment system be designed for DSE that would suit the needs of the modern dairy-farming environment, could this storage system be utilised outside the dairy sector?

2 METHODS

2.1 AERATION AND MIXING

Two aeration/mixing systems were tested, the larger 'MegaJet' and the standard 'KlipJets'.

2.1.1 MEGAJET

Aeration and mixing using 1 MegaJet was undertaken in a KlipTank of 27.5 m diameter, in use on a dairy farm, filled to 1.7 m deep (approx. 990,000 L) with DSE and allowed to settle for 3 days before testing. The MegaJet was operated in aeration mixing mode 4 times over a 120-minute period for 10, 10, 30 and 30 minutes, sample times 1 (prior to jet operation), 2, 3, 4 & 5 respectively.

2 sampling points were used, Site-1 beside the immersed jet and Site-2 opposite the jet. Samples were taken at depths of 300, 1000, and 1400 mm from the surface and to determine the depth of any sludge blanket.

Sampling occurred before operation of the jet (no aeration/mixing). Further sampling occurred after operation of the jets, with a settling period of 2 to 5-minutes being allowed. The settling period allowed the rotational movement of DSE to slow and induced bubble formation to disperse. Sampling was to measure dissolved oxygen (DO), turbidity as total suspended solids (TSS) and pH.

2.1.2 KLIPJET

Aeration and mixing using 3 KlipJets was undertaken in a KlipTank, in use on a dairy farm, of 38.2 metres diameter filled to 1.2 m deep (approximately 1200 m^3) with DSE during the previous 48 hours. Jets were at equidistant spacing around the tank. The KlipJets were operated in aeration mixing mode 3 times over 130-minute period, for 30, 30 and 60 minutes, sample times 1 (prior to jet operation), 2, 3 & 4 respectively.

3 sampling points, positioned beside each immersed jet. Samples were taken at depths of 100, and 800 mm from the surface and to determine the depth of any sludge blanket.

2.2 SOIL AND HERBAGE IRRIGATED DSE

2.2.1 STORED DSE

To determine any effects on soil and herbage, 3 standard KlipJets were installed in a 27.5 m diameter KlipTank and operated 20 minutes per day, over 1 month of standard dairy shed operation. Samples of DSE in the tank prior to any aeration mixing and after 3 days of KlipJet operation were collected. DSE samples were taken from 3 equidistant positions around the tank circumference, at the top, middle and bottom layers of the liquid profile (9 samples). Samples were mixed together thoroughly, from where a composite sample was taken for analysis.

2.2.2 SOIL

4 paddocks were sampled, 2 paddocks that had been irrigated with DSE from the storage tank with no aeration/mixer operation and 2 paddocks that had been irrigated with effluent from the storage tank with the aeration/mixer in operation. DSE was applied for a minimum period of 1 month onto all paddocks. 3 samples of soil using 25 x 75 mm and 25 x 25 mm soil samplers were taken from each paddock and added to the Hill Laboratories sample pack as per instructions. The same 4 paddocks also had herbage samples removed and sent to Hill Laboratories as per the sample pack instructions.

Soil was analysed for pH, Olsen P (%), K, Ca, manganese (Mn), Na, cation exchange capacity (CEC) in me/100g, total base saturation (TBS %), sulphate S (mg/kg), anaerobically mineralised nitrogen (AMN ug/g), organic matter (OM %), total carbon (TC %), total nitrogen (TN %), and carbon to nitrogen ratio (C:N). The soil type was predominantly peaty loam with interspersed sand land layers from geological events.

2.2.3 HERBAGE

Herbage was analysed for percentage of N, P, K, Ca, Mg, Na, S, and mg/kg for iron (Fe), Mn, zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), (Se), and cobalt (Co).

2.2.4 GENERAL

A Teltherm Cerlic multi-tracker was used to determine pH, DO in mg/L and turbidity, ppm (as a measure of total suspended solid), the unit includes a depth detector so that sample depth and any sludge blanket could be determined. The unit was calibrated and washed during sampling with distilled water.

Jet operation was captured on video camera so as to better investigate visual effects post event.

Analysis was performed at Hills Laboratories using Hills Laboratories standard methods for DSE and dairy farm soil and herbage.

3 RESULTS

3.1 AERATION AND MIXING

3.1.1 MEGAJET

A sludge blanket was identified at or about 250 mm from the bottom of the tank, after 10 minutes of aeration/mixing the sludge blanket was no longer detectible. By the end of the third and fourth jet operation cycles the turbidity through the effluent column was approaching uniform consistence; results in Figure 1.

Dramatic increases in DO were recorded over the course of the trial (figure 2) at both sample sites, with a higher increase in DO observed in the surface waters.

The pH of the effluent was 7.24 at 10 minutes from the start and 7.25 after 55 minutes, measured at a depth of 300 mm from the surface at site 1.

At time zero (time 0) The Initial colour of the effluent was dark brown/black, within 2 minutes of aeration mixing settled solids were observed on the service and foam had started to form, a plume of micro-aeration bubbles covered approximately one third of the tanks surface. After 5 minutes' operation a rotational convection flow had stabilised around the perimeter of the tank with a maximum surface speed of approximately 0.5 metres per second. At 40 minutes of operation, foam formation had stabilised and was of a consistent light brown colour and texture. Floating solids (included suspended settled solids) had reduced significantly.

A basic calculation as to DO potential takes the average DO at the end of the trial, minus start average DO to get DO input (mg/L) over 1 hour of aeration mixing. Multiplied by volume of effluent to give total mg O_2 injected.

Injected oxygen divided by the pump kW gives O_2 kg/kW (equation 1.1).

$$1.48 - 0.01 = 1.47 \text{ mg/L}$$

$$1.47 \times 990{,}000 \text{ L} = 1{,}455{,}300 \text{ mg } O_2 \text{ (1.455 kg)}$$

$$1.455 / 8.63 \text{ kW} = 0.137$$

$$0.14 \text{ kg } O_2\text{/kWh pumping energy} \tag{1.1}$$

This does not allow for oxygen used within the system or released into the atmosphere, as micro bubble transfer, it can only be used as a guide to oxygenation potential (kg O_2) per kWh of electrical input.

3.1.2 KLIPJET

The turbidity depth sensor identified a sludge blanket at or about 75mm from the bottom of the tank (approximately 850 mm from the surface). After 30 minutes of aeration/mixing no sludge blanket was measurable. Dissolved oxygen levels increased during the test, averaged results presented in Table 1.

DSE profile where the feed-in is taken from the dairy shed sump then into the storage tank. Results for the sump and un-aerated and aerated DSE are presented in Table 2 & 3.

3.1.3 SOIL AND HERBAGE

Data for soil and herbage analysis is presented in tables 4 & 5 respectively. Samples from land irrigated where the DSE was not aerated and mixed (U/U) and DSE aerated and mixed (A/M) with jets.

3.1.4 INDUSTRIAL AND MUNICIPAL APPLICATION

The composite tank system can be erected in a number of days, one day for the smaller tanks. The lightweight of the composite materials enables minimal foundation work, for liquid storage a sand base is generally all that is required. The design has been refined to meet earthquakes standard NZ1170, with no failures during the recent Christchurch events. Tanks can be supplied to meet importance level 1, 2 and 3 (2012), with a 50-year design life. A composite tank can be depreciated at 16% per annum; full depreciation is therefor 6.25 years. An earth pond depreciation rate is 4% per annum: full depreciation is 25 years.

A number of municipal, industrial and fire fighting water supply storage systems have been installed, using single and multiple tank installations as well a storage for whey, molasses and fracking fluids. The modular design has enabled the installation of tanks on difficult soil types, inside buildings and at remote areas either within budget or where no other easy option was presented.

Modified tanks have been used for wastewater treatment trickle filters on the Chatham Islands and at Waihou WWTP. The lightweight composite design reducing the foundation costs as well as general structure costs, in the case of the trickle filter tower (Photograph 1 & 2).

Covered DSE tanks operate as anaerobic digesters, with a KlipJet and surface scrapper added a DAF system has been developed. A Composite tank system used for an anaerobic digestor or DAF has the potential for a lower capital cost than equivalent steel or concrete systems.

4 DISCUSION

4.1 JET OPERATION

For both the KlipJet and MegaJet systems the sludge blankets present in the tanks were quickly dispersed, with turbidity equalised through the liquid column.

For both jet systems the initial DO was at the lowest detectible levels of the equipment. A dramatic rise in DO was observed as the aeration/mixing test proceeded. DO levels lower in the effluent are in line with the turbidity data and are consistent with the suspended solids settling during the rest period allowed before sampling.

The pH showed no real change over the test period, if any acids were present from anoxic or anaerobic conditions, then these acids were probably too low to effect pH.

Visual observations recorded for the MegaJet were of a large aeration plume, mixing of solids and good stirring movement of the effluent around the tank. Floating solids were broken down so that the effluent had a high consistence of TSS, DO and colour. The break down of solids and general overall condition of the effluent could be due to mechanical action, mixing from the stirring jet, from aeration bubbles and also the maceration effect from the effluent recycle pump supplying the MegaJet.

4.2 STORED DSE

The in-tank concentrations for N, P and Ca are all lower in the aerated/mixed operation period than for the period where no aeration mixing occurred. This is an expected result for increased aerobic action. Sodium is also reduced, most probably as a result of aeration and possibly aerosol loss.

Aerated digestion will reduce N and P as part of bacterial growth and respiration; Ca can be reduced as a result of the calcium-carbonate cycle (often reported as alkalinity) that occurs during bacterial action. The calcium utilised by bacteria, bacteria are filtered out as part of the laboratory analysis thus reducing the calcium that would be detected in the samples.

4.3 SOIL

The soil results for the land that had treated effluent applied had lower AM N, TN and Olsen P but higher Ca, organic matter (OM) and TC, the carbon to nitrogen ratio (C:N) is also higher.
If the lower N, P, Ca figures are the result of bacterial action (in the tank and in the soil) and therefor from treatment we would expect to see lower anaerobically mineralized nitrogen (AM N) as AM N is readily converted to nitrate, nitrite and nitrogen gas by bacteria in aerated water systems (and by soil organisms); lower Olsen P and higher Ca are also expected due to improved bacterial action.

Cation exchange capacity is a complex area of soil analysis and is taken as a measure of the cations and anions as soil colloids. CEC is often incorporated into soil management to assist in determining pH and lime requirements. The larger the CEC the more buffering capacity a soil will have (ability to hold cations) and therefor less lime will be needed to raise the soil pH by a specific amount. Base saturation is also related to CEC where generally the higher the base saturation percentage and CEC, more nutrient will be present and the pH will be higher, this also requires less buffering (Laboratories, 2014, Donahue et al., Tisdale and Nelson, 1975, Adams, 1984, Troeh et al., 1993).

For the soil types on the test farm the pH is considerably higher for the land area where aerated (A/M) effluent was applied, the base saturation for the main cation exchange minerals (calcium and magnesium) were higher than that in the soil irrigated with the non-aerated (U/M) effluent. The soil where the aerated effluent was applied would therefor need less lime to increase the pH and soil colloid holding capacity; mineral leaching would also be less.

In a bacterial treated system N, P and Ca are incorporated into bacterial biomes and respiration gas (N_2) before irrigation as opposed to the soil bacteria having to undertake the conversion. This assumption is strengthened by the higher Ca (now in bacterial biomass as part of the $CaCO_2$ process, so not easily lost); increased organic matter and TN. As the C:N ratio is higher we can assume that although applied N is lower the bacterial treatment occurring during the aeration/mixing cycle has made the conserved nutrient available to the soil.

4.4 HERBAGE

In the herbage samples from land that had treated effluent applied; Ca is lower but is now within the ideal range (0.6 - 1.0), N is lower and just outside the ideal range (4 - 5), sodium (Na) has significantly reduced and is within the ideal range (0.15 - 0.3) all other parameters have reduced slightly and are within range.

Anecdotal evidence from the farm operators was that the animals preferred the herbage from the paddocks irrigated with aeration/mixing treatment over the paddocks irrigated with effluent that had no aeration/mixing.

5 CONCLUSION

Trials using KlipJets and a MegaJet gave positive results for aeration and mixing within the test, dairy effluent, storage tank. This added treatment potential reduced loads to the soil improving the general soil quality as measured by pH, total carbon, readily available nitrogen, reduced sodium levels and improved cation exchange buffer capacity. The resultant herbage has measured mineral parameters now within recommended ranges.

In refining the KlipTank system for DSE storage (130,000 to 4,000,000 L) where cost, simplicity and earthquake resilience are important features; opportunities to supply systems to general storage and wastewater management have arisen.

A system that can be removed or reused and has a similar lifespan to current technologies but at a reduced cost is an important technology that infrastructure managers should investigate. By adding aeration and other additions to meet management needs of DSE we believe Kliptank has developed an innovative way to mitigate some of the range of challenges the water sector faces.

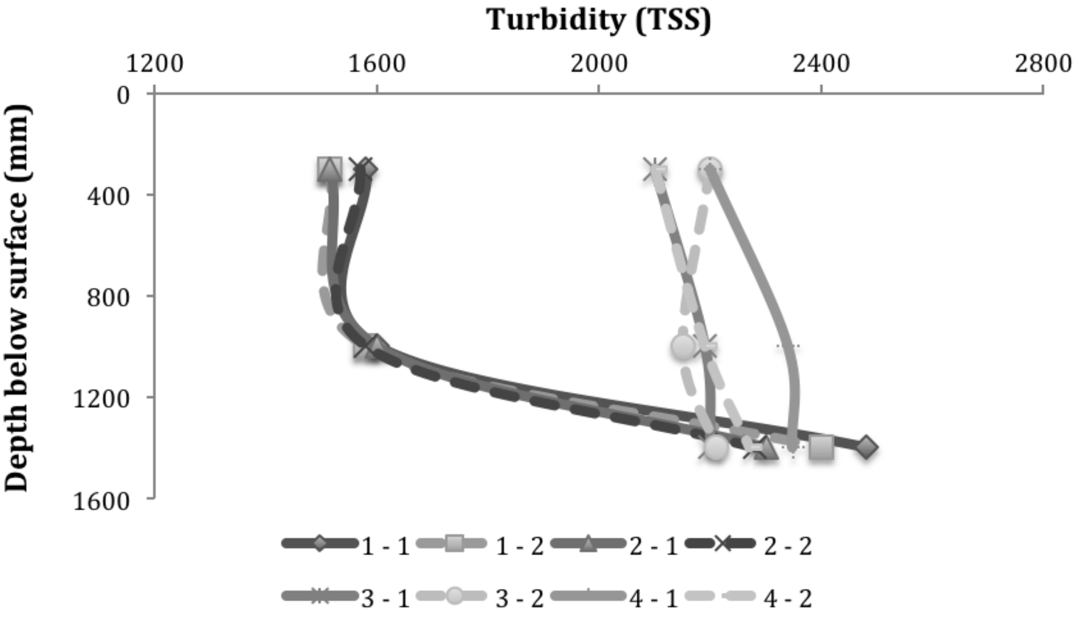

Figure 1: Turbidity recorded for sample times 1, 2, 3 & 4 down through the effluent water column using a MegaJet. Legend key - 1 – 1, first number is sample time, second number is sample site. Sample depth at 300, 1000 and 1400 mm from the surface.

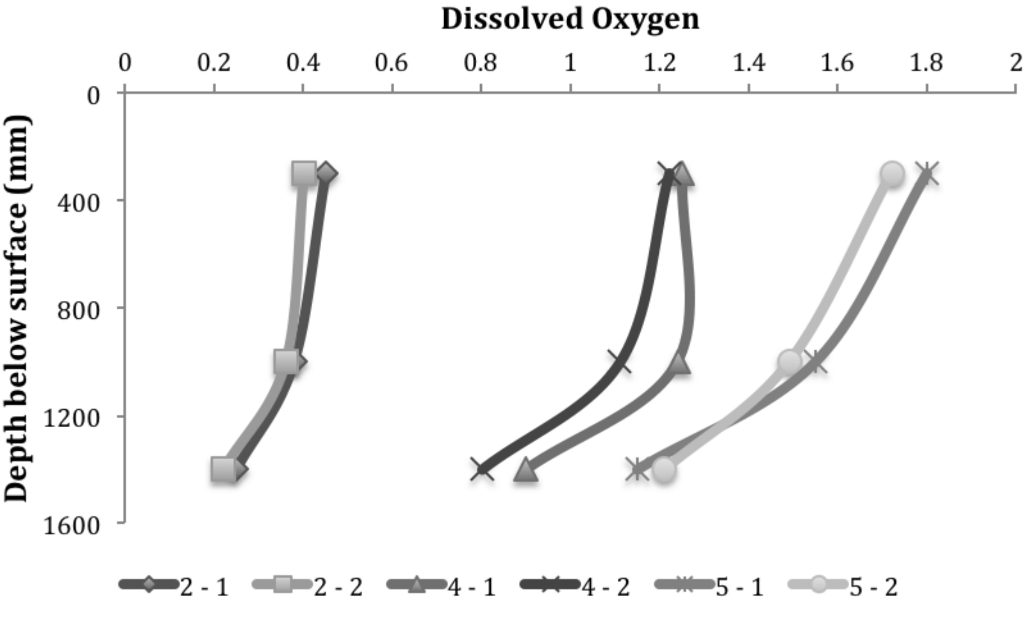

Figure 2: MegaJet dissolved oxygen recorded at sample times 1, 2, 4 & 5 down through the effluent water column. Legend key - 1 – 1, first number is sample time, second number is sample site. Sample depths at 300, 1000 and 1400 mm from the surface.

Table 1: Average turbidity and DO using KlipJets

Sample Time	1	2	3	4

	Depth below surface				
Average Turbidity (TSS)	100	1700	1800	1780	1720
	800	1870	1750	NA	1770
Average DO	200	0.08	0.39	0.37	0.72

Table 2: Dairy shed sump and un-aerated tank stored DSE

	N	P	K	Ca	Mg	Na	S
Sump	0.5	0.101	0.31	0.27	0.089	0.072	< 0.3
Tank	0.3	0.053	0.24	0.21	0.049	0.07	< 1.1

Table 3: Dairy shed aerated tank stored DSE

	N	P	K	Ca	Mg	Na	S
Tank	0.172	0.036	0.22	0.128	0.042	0.068	< 0.3

Table 4: Soil mineral and base saturation data

	pH	Olsen P	K	Ca	Mn	Na	CEC
U/U	5.50	101.33	1.10	7.37	1.68	0.19	24.00
A/M	6.27	76.67	0.93	11.43	1.93	0.16	23.67

	TBS	Sulphate S	AM N	OM	TC	TN	C:N
U/U	43.00	21.33	231.33	13.30	7.73	0.73	10.57
A/M	64.33	5.67	174.67	14.10	8.20	0.66	12.40

Base saturation (%)

	K	Ca	Mg	Na
U/U	4.4	30.7	6.9	0.8
A/M	4.0	51.7	8.4	0.7

Table 5: Herbage element composition data

	N	P	K	S	Ca	Mg	Na	Fe	Mn	Zn	Cu	B	Mo	Se	Co
U/U	4.15	0.41	2.8	0.415	1.305	0.255	0.3905	820.5	87.5	59	13.5	14	1.255	0.421	0.085
A/M	3.7	0.41	3.35	0.335	0.515	0.185	0.1915	472	81	55.5	9	3	1.52	0.2	0.045

Photograph 1: Waitoa WWTP, trickle filter

Photograph 2:   PPG Wrightson, Tuakau; effluent storage tank

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