TRACER STUDIES ON AN AERATED LAGOON

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ABSTRACT

The city of Palmerston North, New Zealand, has two aerated lagoons as its secondary treatment facility. Interest about treatment efficiency led to an investigation into the hydraulics in the second lagoon to determine if further optimisation was viable. A tracer study using rhodamine WT was undertaken to ascertain the stimulus response output. Samples were also taken at 24 points within the lagoon to determine the tracer concentration profile throughout the lagoon. The mean residence time was determined to be 39.9 hours compared to a theoretical residence time of 55.4 hours. Peak concentration of the tracer at the outlet occurred at 0.44 of the mean residence time. The results of the tracer study pointed to 28% of volume being dead space. A subsequent sludge survey indicated that 26% of the design volume of the lagoon was filled with sludge. The internal tracer sampling revealed evidence of localised concentration hotspots in the first 1/3 of the lagoon as the influent enters and mixes into lagoon. The final 2/3 length of the lagoon, however, showed an almost uniform tracer gradient. No evidence of any preferential flow paths from the inlet to the outlet was identified and comparison with the indices from the literature indicated that the lagoons hydraulic efficiency was on par with a baffled system.

KEYWORDS

Aerated lagoon, tracer, short-circuiting, hydraulics

1 INTRODUCTION

The effectiveness of treatment in aerated lagoon systems is strongly dependent on the internal hydraulics of the system, as this defines the contact time between the incoming waste and the active biomass. However, any hydraulic short-circuiting can have a significant detrimental impact on treatment efficiency because the rate of treatment is typically proportional to the remaining concentration of pollutant (i.e. first order kinetic behaviour). For this reason if a small quantity of pollutant reaches the outlet too quickly via a preferential flow path (short-circuiting) it can make a large contribution to the final pollutant concentration in the effluent (Shilton and Harrison 2003a). Despite the widespread application of aerated lagoons, there have been very few hydraulic studies of any type (Delatolla and Babarutsi 2005; Dorego and Leduc 1996; Nameche and Vasel 1998). In the few studies that have been conducted, the favoured method for investigating the hydraulics of aerated lagoons has been the stimulus-response tracer technique. The output from a stimulus response tracer test is known as an "E curve" or residence time distribution (RTD). While an RTD can provide such parameters as the mean residence time (MRT), stimulus–response tracer studies are essentially "black box" techniques and can give only very limited qualitative detail about the internal flow patterns within the lagoons.

Various researchers have attempted to derive qualitative data from E curves by the use computer modelling that simplifies the hydraulic flow regime in terms of a number of hypothetical cells within the pond (Burrows et al. 1999; Crohn et al. 2005). It is however debatable whether this approach really gives any significant practical insight into the true nature of the internal flow pattern. Alternatively, Texeira and Siquera (2008) compared various hydraulic indices and recommended the use of t_{10}, which is the time taken for 10% of the tracer to leave the pond and the dispersion index (σ^2) as reliable indices for defining the degrees of short-circuiting and of mixing respectively. They proposed that these indices could then be used to define the pond as one of five different hydraulic regimes. A far better understanding of internal flow patterns would, of course, be obtained by actually mapping the tracer distribution within the lagoon basin itself as it moves through the system. Only one prior study has monitored tracer concentration within a lagoon (Delatolla and Babarutsi 2005), however this work was limited to just six locations and was not designed to map variations in tracer concentrations throughout the lagoon.

This paper presents the results of a stimulus-response tracer test and extensive internal sampling of tracer from within the aerated lagoon itself.

2 MATERIALS AND METHODS

2.1 TRACER STUDY

This study was undertaken on Lagoon 2, a 2.5 ha, 82,000 m^3 *partially mixed* aerated lagoon at the wastewater treatment plant in Palmerston North, New Zealand (40°23'12"S 175°34'45"E). Note, that the term *partially mixed* is based industry standard definitions for energy input per unit volume. The lagoon has a nominal residence time of 3.8 days at average daily flow. Lagoon 2 receives the effluent from Lagoon 1 which is a fully mixed 36,000 m^3 aerated lagoon treating primary treated effluent from the city of Palmerston North (pop. 73,000). Lagoon 2 is aerated using three 30 kW surface aerators placed in the first 2/3 of the lagoon.

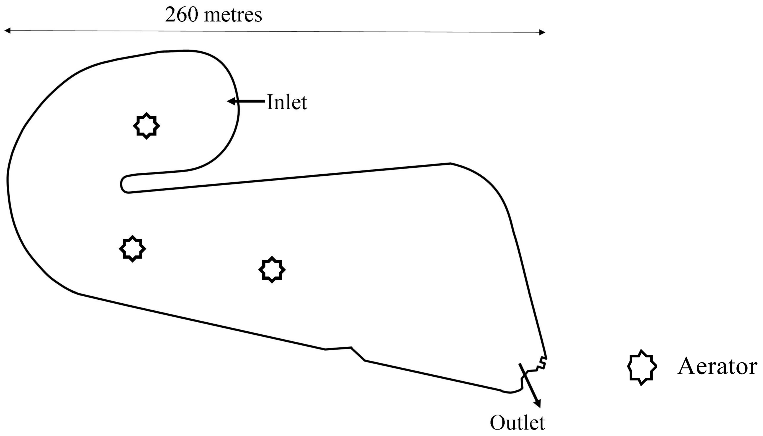

Figure 1: Schematic representation of aerated lagoon 2

A tracer response study was carried out on lagoon 2. 10 L of rhodamine WT (20% active ingredient) was diluted with 40 L of lagoon water, to equilibrate the temperature and mixed density of the tracer with the influent. It was then added via the inlet pipe entering the lagoon. Samples were taken from the outlet channel using an ISCO 3700 Standard Portable Sampler. To ensure accurate recording of the time to the appearance of the first tracer at the outlet, sampling was initially every 15 minutes. Sampling intervals were increased to every ½ hour on day 3, every hour on day 5, after day 11 samples were taken every 6 hours.

Samples were also taken at 24 points throughout the lagoon to determine tracer concentration within the lagoon itself. Two sampling runs were undertaken. The first sampling run was undertaken 3 hours after the application of the tracer, while the second was completed 26 hours after application. The sample collection was completed within a hour. The sampling depth was 0.5 m.

A Shimadzu Spectrofluorophotometer was used to determine tracer concentration (absorbance wavelength 530 nm, emission wavelength 555 nm).

2.2 SLUDGE SURVEY

A sludge survey was carried out using the "white towel technique" (Malan 1964). A five metre pole with a white rag attached to its length was pushed to the base of the lagoon and then retracted. The depth of lagoon as well as the depth of sludge was determined from the discolouration of the white rag. Lateral position was determined with a Garmin eTrex Legend global positioning system device. Sludge volume was determined by extrapolation between data points and integration of the resultant surface using $5m^2$ area units.

3 RESULTS AND DISCUSSION

3.1 TRACER STUDY

Over the period of the tracer study the theoretical hydraulic residence time (HRT) was determined to be 55.4 hours. This was based on V/Q where V was the design volume (82,000 m^3) and Q was the total flow of water over the test period. The normalized tracer response measured at the outlet of lagoon 2 is shown in Figure 2 below.

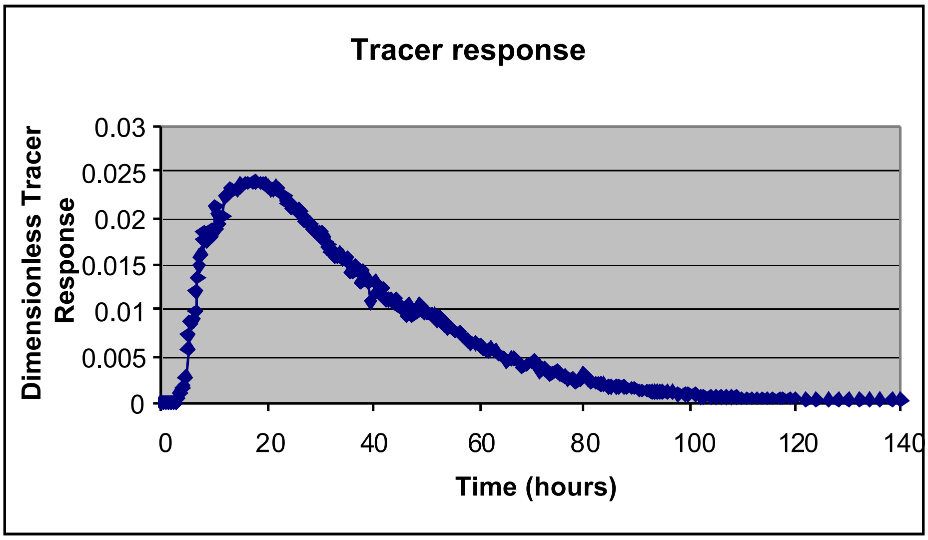

Figure 2: Normalised hydraulic residence time distribution.

The tracer response showed a well defined curve with no spikes before or after the main curve. The time to initial detection was 3.0 hours. The time taken for 10% of the tracer dye to leave the pond (T_{10}) was calculated at 10.5 hours or 0.26 of T_{mean}. This is close to the index figure identified by Texeira and Siquera (2008) as being indicative of a fully baffled pond. The curve then rises steeply to the peak tracer concentration at 17.5 hours or 0.44 of T_{mean}. According toTeixeira and Siqueira (2008) this is more indicative of pond which has baffles at the beginning of the pond. After this point there is a steady decline to about 85 hours when 95% of the measured tracer had passed through the lagoon. This is followed by the long, shallow tail of the curve (representing dilution and washout of the mixed tracer) which continued to 381.5 hours when the last of the tracer was detected. After three residence times (119.4 hours in total) only a further 2.2 % of the tracer was detected. In total over 99% of the tracer was accounted for.

The mean residence time was calculated using the method given by Levenspiel (Levenspiel 1972):

$T_{mean} = \Sigma t_i C_i dt / \Sigma C_i dt$

where:

t_I = time of measurement;
C_i = concentration at the time of measurement;
dt= the time between consecutive measurements.

This was determined to be 39.8 hours. However this assumes conditions of constant flow, which rarely occur in a working wastewater treatment plant. Indeed over the course of the experiment the flow varied from 235 L/s to as high as 726 L/s due to rain (Figure 3).

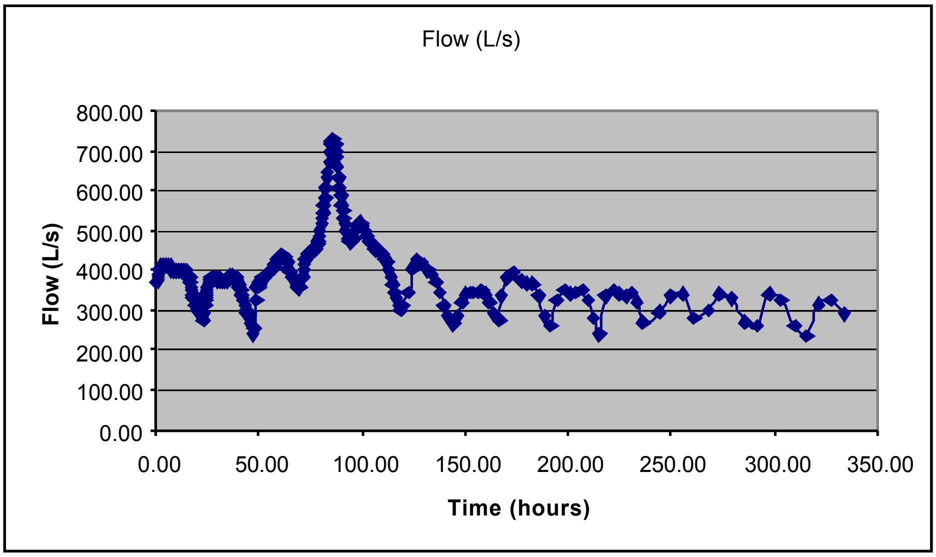

Figure 3: Influent flow over the course of the study

As accurate flow measurements were available throughout the period of the tracer study, concentration was able to be converted to mass of tracer and the mean residence time was calculated using

$T_{mean} = \Sigma t_i Q_i C_i \mathrm{d}t / \Sigma Q_i C_i \mathrm{d}t$

where: Q_i = flow at time of measurement.

Using this method the mean residence time was determined to be 39.9 hours. This is very close to the figure derived using the Levenspiel method indicating that variations in flow had only a minor affect on the determination of the mean residence time. This may be due to the fact that the high flow event did not actually occur until after 95% of the tracer had already left the lagoon.

Using the mean residence time calculated from the experimental data and the flow rate for the period of the tracer study, the effective liquid volume in the lagoon was calculated to be 59,073 m^3. A common mistake in tracer studies is that they are finished too early and the missing tracer leads to misreporting of dead space (Shilton and Sweeney 2005). However in this study almost all of tracer (>99%) was accounted for and thus the difference between the available volume and the design volume will most likely be due to sludge buildup. This was subsequently confirmed with the predicted dead space (28%) being in very close agreement the sludge volume (26%) derived from the physical sludge survey.

Table 1: Hydraulic parameters derived from tracer study.

Parameter	
Time to first detection at outlet	3.0 hours (0.08 of T_{mean})
T_{10}, time taken for 10% of the tracer to leave the pond	10.5 hours (0.26 of T_{mean})
Time to peak concentration	17.5 hours (0.44 of T_{mean})
Mean residence time (T_{mean})	39.8 hours
Flow corrected mean residence time	39.9 hours
Theoretical residence time	55.4 hours
Dead space	28% of design volume

The short time between tracer input and first detection at the outlet (3.0 hours or 8% of T_{mean}) may be a result of efficient mixing (for a perfectly mixed system the time to first detection is theoretically instantaneous), or the result of short-circuiting. However, the gradual slope of the front of the curve appears to indicate that it is in-pond mixing rather than any significant short circuiting along a preferential flow path which is enabling some of the tracer to exit the pond relatively quickly. Furthermore, if a flow path were circulating past the outlet, a common hydraulic phenomena that results in short-circuiting is the formation of large horizontal circulating cells (Shilton and Harrison 2003b), this would have resulted in a response peak on the first pass of the outlet with secondary peaks on subsequent passes (Dorego and Leduc 1996), but none were observed. Secondary peaks can also be caused when main flows are split into isolated flow patterns which are not well mixed by the time they reach the outlet. The smooth shape of the front and back of the tracer response curve indicates that the tracer was well mixed into the effluent by the time the flow reached the outlet.

3.2 TRACER CONCENTRATION WITHIN THE LAGOON

A tracer distribution profile taken after 3 hours is shown in figure 4. Several localised tracer concentration ‘hotspots’ around the first aerator can be seen as the tracer circulates in this front section of the lagoon before becoming well mixed. There does appear to be higher tracer concentrations on the northern bank, between the 2nd and 3rd aerators. Rather than being due to any particular short circuiting, this is more likely attributable to the action of the 3rd aerator entraining low concentration liquid from the end of the pond along the south bank back against the main flow from inlet to outlet. The north eastern zone appears quiescent and outside the main flow. The concentration front is relatively broad and flat as it approaches the outlet indicating that the tracer is well mixed into the lagoon by the time it reaches this point.

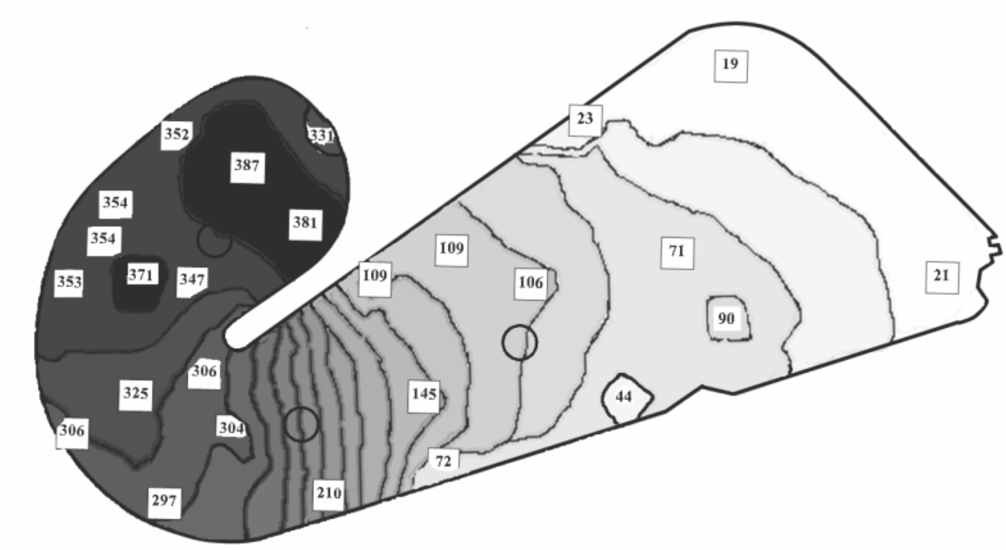

Figure 4: Tracer distribution profile 3 hours after application (fluorescent intensity units). Shading is illustrative only.

Figure 5 shows the tracer distribution profile 26 hours after application. The tracer has swept through the system and concentrations now increase down the length of the lagoon while staying fairly uniform across the width. A significant level of tracer concentration was still detected at the inlet end and will have remained until diluted by influent and washed out with the effluent creating. It is the dilution and washout of well mixed tracer that creates the long tail on the tracer response shown in Figure 2. The second 2/3 of the lagoon shows little evidence of localized concentrations indicating that the lagoon is quite uniformly mixed in this region with no evidence of preferential flow paths.

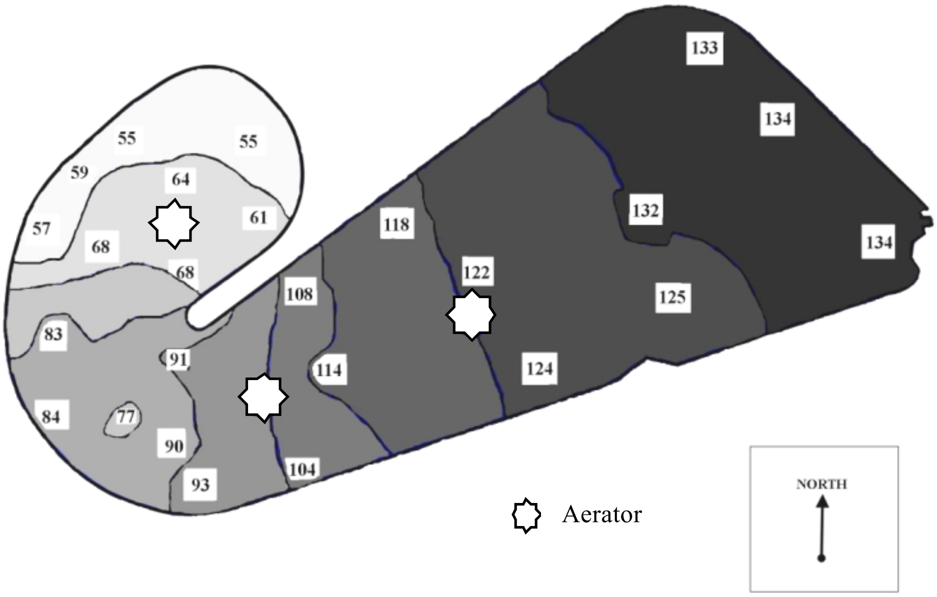

Figure 5: Tracer distribution profile 26 hours after application (fluorescent intensity units). Shading is illustrative only.

CONCLUSIONS

- The mean residence time was 39.9 hours, substantially shorter than the theoretical residence time of 55.4 hours. This indicated a dead space of 28% of the design volume. This was in good agreement with a sludge survey of the same lagoon which measured a sludge volume of 26 %.
- Tracer was detected 3 hours (0.08 of mean residence time) after application however this was attributable to the effect of mixing by the aerator rather than being during to any specific short-circuiting via preferential flow path.
- The time to peak concentration of tracer at the outlet was 17.5 hours (0.44 of the mean residence time).
- Internal sampling of tracer showed that there were localised areas tracer hotspots present in the first 1/3 of the lagoon as the influent becomes well mixed into the rest if the lagoon but in the final 2/3 portion of the lagoon there is a uniform concentration gradient approaching the outlet.
- Comparison with the indices from the literature indicate that the lagoons hydraulic efficiency was on par with a baffled system.

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REFERENCES

Burrows, L. J., Stokes, A. J., West, J. R., Forster, C. F., and Martin, A. D. (1999). "Evaluation of different analytical methods for tracer studies in aeration lanes of activated sludge plants." *Water Research*, 33(2), 367-374.

Crohn, D. M., Ruud, N. C., Decruyenaere, J. G., and Carlon, D. B. (2005). "Goodness-of-fit test for modeling tracer breakthrough curves in wetlands." *Journal of Environmental Engineering-Asce*, 131(2), 242-251.

Delatolla, R. A., and Babarutsi, S. (2005). "Parameters affecting hydraulic behavior of aerated lagoons." *Journal of Environmental Engineering-Asce*, 131(10), 1404-1413.

Dorego, N. C., and Leduc, R. (1996). "Characterization of hydraulic flow patterns in facultative aerated lagoons." *Water Science and Technology*, 34(11), 99-106.

Levenspiel, O. (1972). "Chemical Reaction Engineering (ed.)." Wiley, New York.

Malan, W. M. (1964). "A guide to the use of septic tank systems in South Africa." In: *CSIR Research Report No. 219*, National Institute for Water Research, Pretoria.

Nameche, T., and Vasel, J. L. (1998). "Hydrodynamic studies and modelization for aerated lagoons and waste stabilization ponds." *Water Research*, 32(10), 3039-3045.

Shilton, A., and Sweeney, D. (2005). "Hydraulic design." In: *Pond Treatment Technology*, A. Shilton, ed., IWA Publishing, London, 188-215.

Shilton, A. and Harrison, J. (2003a). Integration of coliform decay within a CFD model of a waste stabilisation pond. *Water Science and Technology*, Vol. 48, No. 2, 205-210.

Shilton, A. and Harrison, J. (2003b). Development of guidelines for improved hydraulic design of waste stabilisation ponds. *Water Science and Technology*, Vol. 48, No. 2, 173-180.

Teixeira, E. C., and Siqueira, R. D. (2008). "Performance assessment of hydraulic efficiency indexes." *Journal of Environmental Engineering-Asce*, 134(10), 851-859.