Kingston on Murray: A facility to enable comparison of the performance of a community wastewater management waste stabilisation pond and a high rate algal pond.

H.J. Fallowfield and N.J. Cromar

Department of Environmental Health, School of Medicine and the Flinders Research Centre for Coastal and Catchment Environments, Flinders University, GPO Box 2100, Adelaide 5001, South Australia, Australia
(Email howard.fallowfield@flinders.edu.au; nancy.cromar@flinders.edu.au;)

Abstract

The treatment of sewage in rural communities in South Australia, depends upon primary treatment in septic tanks with subsequent treatment of the liquid phase in community managed facultative and maturation ponds. The facultative pond is operated at a depth of 1.2m with a residence time of 36 days. The 4 cell maturation ponds are operated at the same depth with a combined residence time of 30 days. Comparison with other design criteria suggests that the design areal loading rates are 120 – 138kg BOD_5/ha/d which are similar to other published design criteria. Waste stabilisation ponds (WSP) are unmixed systems. A review of the literature demonstrates that hydraulic short circuiting coupled with the stratification of temperature, dissolved oxygen and pH can adversely affect treatment performance. Mixed, high rate algal pond (HRAP) systems yield more homogeneous physical and chemical environments in which improved treatment performance may be anticipated. The community waste management system at Kingston on Murray, South Australia has been designed to enable the first on-site comparison of the performance of a WSP and HRAP system.

Keywords : Waste stabilisation ponds, high rate algal ponds, comparison of performance, wastewater treatment

Community Waste Management Schemes in South Australia

Some 180,000 rural South Australians depend upon about 130 Community Wastewater Management Systems (CWMS) for sewage treatment. Primary treatment is effected on individual properties by on site septic tanks and the liquid phase is further treated in centralised waste stabilisation ponds (WSPs) managed by the local authority. The treated effluent is reused, commonly for irrigation of woodlots.

Design criteria for Community Wastewater Management Systems (CWMS) WSPs.

The septic tanks are designed to meet The South Australian Environmental Health Branch Guidelines (1995). These require a minimum detention time of at least 24 h with the objective of removing 60% - 70% of the suspended solids (SS) and 30% of the BOD_5. The design criteria used for septic tanks, suitable for a typical residential dwelling, are a minimum daily inflow or hydraulic load of 150 L/capita/d with the daily inflow based on not less than six persons. These guidelines typically result in a $3m^3$ septic tank which requires de-sludging, which is normally managed by the local authority, every 4 years. The liquid phase from the septic tank is discharged for further treatment to the CWMS waste stabilisation ponds. The removal of suspended solids enables the use of small diameter plastic pipes (100mm) at a minimum grade of

0.4%. Palmer et al (1999) estimated that the capital cost of construction of a CWMS was 60% less per connection than that for connection to country sewerage schemes.

The design for the Community Waste Management System (CWMS) lagoons originates from WSP research conducted by Marais in the early 1970s. The design criteria assume a BOD_5 of 50 g/capita/d nominally equivalent to a concentration of 360 mg BOD_5/L at a dry weather flow of 140 L/capita/d (South Australian Department of Health, undated). These criteria specify a 5 cell WSP with 2:1 length to width ratio. The first lagoon is required to have a retention time (θ) of 36d with the four additional lagoons each having a θ of 7.5d. The recommended depth for the lagoons is 1.2m. The treated discharge criteria are 20mg BOD_5/L and 30 mg SS/L. The microbiological quality is dependent upon discharge environment or end use for irrigation.

The township of Kingston on Murray (34°13'18.56"S, 140° 20'52.70''E) lies 208 km north east of Adelaide. The design criteria for the CWMS lagoons were used to compare the South Australian Environmental Health Branch Guidelines (EHBG, 1995) with those used elsewhere. The implied facultative lagoon areal loading rate was calculated using Equation 1 (Mara and Pearson, 1998),

$$L_s = \frac{10\ BOD_5\ Q}{A} \qquad \text{(Eq. 1)}$$

Where: Ls = facultative lagoon areal loading rate (BOD_5 kg/ha/d); BOD_5 = 360 mg BOD_5/L; Q = Kingston on Murray daily flow 60 m^3 /d and A = area (θ.Q/d; m^2).

The calculations implied that the EHBG (1995) guidelines were equivalent to a facultative lagoon areal loading rate of 120 kg BOD_5/ha/d equivalent to that recommended by Mara and Pearson (1998) for pond operated at 12°C. Assuming the maximum water temperature at Kingston on Murray was 10 and 22°C respectively and using the recommended areal loading rate of 100 kg BOD_5/ha/d at 10°C for 360 mg BOD_5/L (Mara and Pearson, 1998) the calculated retention time required was 43 d.

However, measurement of effluent values at Kingston on Murray suggested that the actual BOD_5 was 416 mg BOD_5/L (25 kg BOD_5/d), compared with the nominal value of 360 mg BOD_5/L suggested in the guidelines. Assuming similar seasonal water temperatures, an areal loading rate of 100 kg BOD_5/ha/d for 10°C (Mara and Pearson, 1998) and a pond depth of 1.2m the facultative lagoon design retention time was calculated at 50 d. This retention time was approximately 40% greater than the 36 d stipulated in the EHBG (1995). The loading rate under these conditions, using Kingston on Murray data, necessary to achieve the EHBG (1995) desired θ of 36d was 138 kg BOD_5/ha/d. The analysis suggested that the EHBG (1995) result in reduced area requirements compared to other design criteria. These guidelines imply an area requirement of 4.4 m^2 / capita, whereas French designs for facultative pond loading have recommended 6m^2 per person, which is equivalent to the outcome for Kingston on Murray using the actual design criteria and an areal loading of 100 kg BOD_5/ha/d at 10°C using design criteria of Mara and Pearson (1998).

Comparison of maturation pond design approaches lead to similar area requirements 1,735 m^2 (Mara and Pearson, 1998) compared with the LGA design of 1,500 m^2.

Residence times are also similar 30 and 35 days for the LGA and Mara and Pearson (1998) respectively. The microbiological discharge criterion for woodlot irrigation was 1000 faecal coliforms / 100ml.

Waste stabilisation pond hydraulic characteristics.

These systems are relatively shallow and unmixed and as a consequence experience thermal stratification, where temperature may differ by 12°C between the lagoon surface and bottom (Sweeney et al, 2005). This also results in dissolved oxygen stratification with aerobic and anaerobic conditions occurring at the surface and bottom of the lagoon respectively. These variations in conditions throughout the depth influence the reaction rates of key treatment processes such as nutrient and BOD removal (Sweeney et al, 2007) and pathogen die-off (Sweeney et al, 2005). These systems may also suffer hydraulic short-circuiting (Fig 1), producing retention times shorter than those designed, which may result in insufficient treatment of the effluent (Sweeney et al, 2003). There is a paucity of data regarding the performance of CWMS lagoons in South Australia. What is available is largely compliance monitoring data from the outfalls from which treatment performance cannot be derived since wastewater input data is not routinely collected. Many of the potential performance issues associated with WSP are a consequence poor hydraulic flow conditions and the absence of mixing to maintain a homogeneous physical and chemical environment.

High Rate Algal Ponds

High rate algal ponds (HRAPs) are shallow, mixed systems consisting of a series of interconnecting baffled channels. The process of mixing, using a paddlewheel to achieve a linear velocity of about 0.2 ms^{-1}, avoids thermal stratification and produces a more a homogenous chemical environment throughout the pond. These conditions result in high rates of algal photosynthesis and consequently dissolved oxygen production. This leads to the potential for more rapid treatment and /or higher organic loading rates. The higher treatment reaction rates result in shorter retention times and consequently reduced area requirements for the same degree of treatment compared to unmixed lagoons such as WSPs. HRAPs have other potential advantages: firstly the reduced surface area minimises evaporative losses and improves the water balance for irrigation. Secondly, in addition to improving the photosynthetic potential, which is significant since photosynthesis is the major source of dissolved oxygen in the pond, the gentle mixing increases the rate of atmospheric oxygen diffusion into the pond at night compared with unmixed systems, maintaining an aerobic environment.

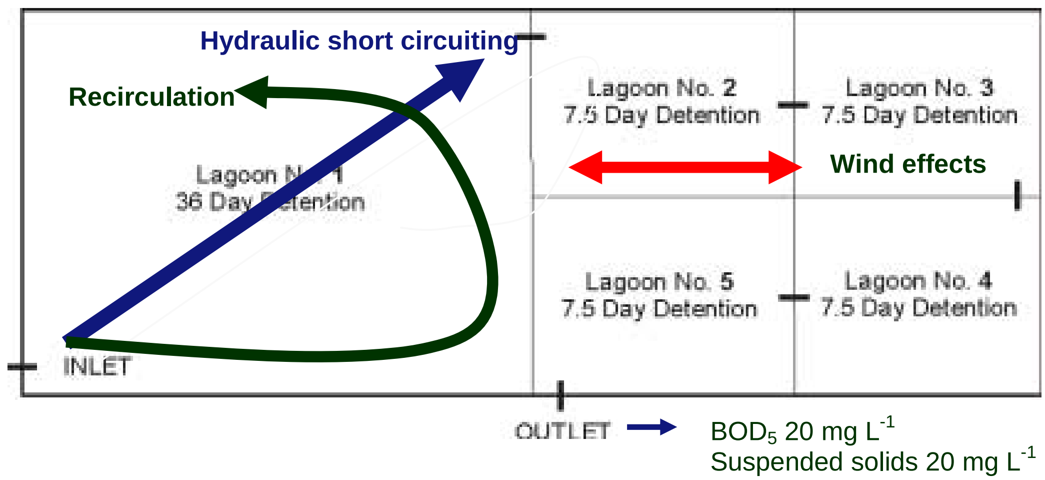

Figure1. The potential processes influencing hydraulic retention time in 5 cell waste stabilisation ponds employed to treat septic tank effluent in Community Waste Management Schemes.

HRAPs research has largely focussed on their ability to treat high strength effluents; a consequence of the potential for them to accept higher organic loading rates. HRAPs have been shown to treat a variety of high strength industrial and agri-food effluents. High nutrient and BOD/COD removal rates are achieved in HRAPs. Fallowfield & Garrett (1985) reported BOD_5 removal of 98%, and maximum N and P removals of 98 and 89% respectively when using an HRAP to treat piggery effluent under Northern Ireland climatic conditions. Similarly, Cromar *et al* (1996) reported a mean BOD_5 removal of 90% in an experimental HRAP operating in Scotland on a synthetic sewage at a loading of 250kg COD ha^{-1} d^{-1}. Subsequently, HRAPs operating at loading rates of 100-600 kg COD ha^{-1} d^{-1} showed nitrogen removals of 78 -95% and a maximum phosphorus removal of 55% at a retention time of 7 days (Cromar & Fallowfield, 1997). The ponds also demonstrated significant nitrification. Fallowfield *et al* (1999) showed nitrogen removal to be strongly correlated with algal biomass within the HRAP. HRAPs operating at Murray Bridge in South Australia for the treatment of strong abattoir wastewater demonstrated that BOD_5 removal was between 95 – 99%. Removal efficiencies for COD were also substantial, ranging from 73 – 80% with removal efficiencies for nitrogen ranging from 50 – 60% (Fallowfield *et al.* 2001).

A significant feature of this ‘high rate’ lagoon technology over WSPs are the elevated rates of photosynthesis brought about by gentle mixing, which produce supersaturating DO levels and high diurnal shifts in pH with values as high as pH 11 being recorded. This combination, together with greater exposure of the pond volume to UV irradiation, results in the rapid death of indicator organisms such as thermotolerant coliforms and *E.coli* (Curtis *et al*, 1992; Fallowfield *et al*, 1996). While many rate constants for the removal of pathogens and faecal indicators are determined using empirical modelling of existing waste stabilisation lagoon systems, few studies have measured die-off rate constants (K_b) in HRAPs. However, K_b values for *E. coli* of 0.3 – 10.26 d^{-1} were measured in HRAPs operating in Scotland, for the treatment of piggery wastewater (Mamparayane *et al* 1989, Fallowfield *et al* 1996), in HRAPs operated at mean pond temperatures of between 14 and 19ºC at surface irradiances of 85 – 356 Wm^{-2}. These temperature conditions are comparable with those of HRAPs operated in South Australia where pond temperatures range from 14 - 25 ºC (Evans *et al*, 2003), however, the irradiance may be even more favourable to bacterial die-off in Australia.

Von Sperling notes that the flow patterns of lagoon systems may well be better characterised using a dispersed flow model rather than the more conventional CSTR. The flow patterns in HRAP induced by the paddlewheels ensure that these systems are fully mixed at all times (Fearnley *et al*, 2004) and thus they may be seen to more closely resemble the dispersed flow model of Yanez *et al* (1993) and others in die-off kinetics (von Sperling 1999).

Comparison of the performance of Waste stabilisation ponds and high rate algal ponds.

WSPs and HRAPs have been operated independently in various parts of the world. Fallowfield and Garrett (1985) performed a desk study using HRAP data from California and WSP data from Israel to compare the performance of mixed and unmixed systems. This demonstrated that the HRAP mixed system offered the potential to significantly reduce area requirements by up to 75% where the minimum monthly treatment temperature was 12°C – similar to that at Kingston on Murray. However, the authors are unaware of any studies comparing the performance of these systems, side-by-side in the same location treating the same effluent, anywhere in the world. The Local Government Association of South Australia and Loxton Waikerie Council, have provided this opportunity by constructing a WSP and an HRAP in the new CWMS constructed at Kingston on Murray to enable comparison of the performance of the two systems treating 60 m^3 of effluent per day.

The Kingston on Murray CWMS is designed to treat effluent (60m^3/d, 25 kg BOD_5/d) from ca. 100 properties. The effluent is initially treated at the properties by an on-site septic tank and the liquid phase is pumped to the CWMS. The CWMS comprises 1600m^2, 1.2 m deep, five-cell WSP designed using LGA Guidelines. The combined residence time of this system is 66 days. The HRAP, designed by the authors, is 600m^2 and can be operated at variable depth (nominally 0.6 m) and mixed by a variable speed paddlewheel. The wastewater retention time in both systems can be varied by adjusting the flow to the respective systems, controlled via an effluent splitter box. The nominal retention times in the HRAP can be varied between 7-12 days. Influent and effluent flows are recorded using Mag-Flo meters. The treated effluent from both systems is held in a storage lagoon prior to reuse for irrigation of an onsite woodlot. Remote sensing of pH, DO, temperature will be conducted in both the WSP and the HRAP systems. A logging weather station (irradiance, wind speed/direction, temperature) is also installed at the site.

The Kingston on Murray HRAP configuration is:

- Designed at influent BOD_5 loading rates within the mid-range of acceptable rates for HRAPs
- Calculated to meet the thermotolerant coliform removal criteria for C class effluent (1000/100ml)

- Designed to reduce the land area requirement compared to the CWMS facultative pond from $1800m^2$ to $600m^2$ while achieving similar if not improved BOD_5, nutrient and pathogen removals
- A conservative HRAP design to function as a comparison alongside an example of the WSP systems currently operated by LGA

The Kingston on Murray CWMS will enable research to:

- To compare the effluent treatment performance of a CWMS lagoon with an HRAP at Kingston on Murray.
- To determine the optimum operating conditions to maximise HRAP performance.
- To provide design criteria for HRAP design and operation in South Australia and elsewhere with similar climatic characteristics.

The system also provides significant opportunities for international collaboration.

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