Algal Research 35 (2018) 325–332

Contents lists available at ScienceDirect

Algal Research

journal homepage: www.elsevier.com/locate/algal

Performance of a high rate algal pond treating septic tank effluent from a community wastewater management scheme in rural South Australia

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ARTICLE INFO

Keywords:
Microalgae
Wastewater treatment
Biomass
High rate algal pond

ABSTRACT

A high rate algal pond (HRAP) incorporated into a community wastewater management scheme was operated over two years in the Mediterranean climate of Kingston on Murray, South Australia. Uniquely, the study evaluated the performance of the HRAP when fed ($12\,m^3\,day^{-1}$) either treated effluent from on-site septic tanks or a facultative pond further treating the septic tank effluent from within the community (population 300). The influence of depth and season on wastewater treatment and biomass production were determined for both configurations. Generally, wastewater treatment (> 90% BOD_5 removed) and biomass production ($31.7\,g\,m^{-2}\,day^{-1}$) was improved when the HRAP was fed septic tank effluent. PO_4-P removal was low and effected by biomass uptake rather than precipitation. Inorganic nitrogen removal was independent of depth in the warmer months and inversely related to depth in the colder months. The mean $\log_{10}$ removal values for *Escherichia coli* were 1.75 and 2.75 for the HRAP when fed septic and facultative pond effluent respectively. In the prevailing Mediterranean climate, adequate BOD_5 and nitrogen removal, and disinfection assessed using *E. coli* as the faecal indicator organism was achieved at 0.32 m depth at a retention time of 4 days.

1. Introduction

In South Australia, rural wastewater treatment needs are met by 172 Community Wastewater Management Schemes (CWMS) which treat effluent from a combined population of 180, 000. The CWMS treatment train commences with residential, on-site septic tanks for primary treatment. Potential environmental and public health issues associated with on-site disposal of the treated liquid phase are managed by reticulating the septic tank effluent to centralised systems. Over 50% of the 172 CWMS incorporate waste stabilisation ponds (WSP).

High rate algal ponds (HRAPs) are shallow, mixed systems consisting of a series of interconnecting baffled channels [1]. Mixing by paddlewheel avoids thermal stratification and produces a homogenous chemical environment within the pond. This environment is conducive to high rates of algal photosynthesis and consequently more rapid treatment, reduced land area requirements and capital cost for construction compared with the deeper unmixed WSP [2–6].

There are surprisingly few studies in the literature which explicitly determine the optimum depth and theoretical hydraulic retention time (THRT) for HRAP wastewater treatment and algal biomass production. In tropical regions where these parameters are relatively constant Oswald [7] suggested that HRAPs could be successfully operated at a constant depth and residence time. In more variable Mediterranean climates, he suggested operating HRAPs at a greater depth in winter (to increase retention time) since the algal concentration is lower and theoretically light penetration through the water column should be greater thereby maintaining disinfection [8–11]. Craggs et al. [12] noted that the disinfection performance was similar for two adjacent HRAPs, albeit of different surface areas, operated at a THRT of 7.5 days at depths of 0.3 m and 0.45 m. These results imply disinfection was independent of depth. However, seasonal influences on performance were not reported. In contrast, El Hamouri et al. [13] operating HRAPs in Morocco at depths of 0.3, 0.5 and 0.6 m with retention times of 3 days and 6 days in the hot and cold seasons respectively reported disinfection was greatest at the shallowest of the three depths. Picot et al. [10] operated a small HRAP in southern France for the treatment of relatively low strength domestic wastewater and showed that at a constant depth of 0.35 m increasing retention time from 4 days in summer to 8 days in winter maintained treatment performance. More recently, Sutherland et al. [14] compared the performance of small ($2.23\,m^2$) HRAPs operated simultaneously at 0.2, 0.3 and 0.4 m depths, through winter, spring and summer at Hamilton, New Zealand. The

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[1] Dr Neil Buchanan who conducted this work in fulfilment of his PhD candidature at Flinders University is deceased.

https://doi.org/10.1016/j.algal.2018.08.036
Received 13 December 2017; Received in revised form 22 August 2018; Accepted 30 August 2018

HRAPs were fed wastewater of indeterminate strength. All three pond depths were operated in each season, and the retention times were the same for all ponds within a season but varied between seasons; with all ponds having retention times of 9 days (winter), 6 days (spring) and 4 days (summer). They concluded that when operated at 0.4 m algal productivity was increased, wastewater treatment was more cost-effective and treated wastewater quality was not compromised. Albeit, the utility of this conclusion for HRAP wastewater treatment management is undermined by the seasonal variation of retention time confounding the results. Normally, daily wastewater flow rates, in the absence of stormwater or groundwater infiltration, are relatively constant as is the operational area of a HRAP. Under these conditions, at a constant depth, it is not possible to change retention time by changing flow rate [15–19].

HRAP technology may be applied to new CWMS or be retrofitted to existing schemes as part of a planned upgrade program. Uniquely, here we present the results from a CWMS which incorporates a HRAP to treat effluent from the South Australian township of Kingston on Murray. The performance of an HRAP integrated into a CWMS and operated at 3 different depths was evaluated when receiving two different sources of inlet wastewaters at constant flows; firstly, when directly receiving effluent pre-treated in on-site septic tanks and secondly, when receiving effluent from a facultative WSP (30 day THRT) which had treated effluent from the on-site septic tanks within the community of Kingston on Murray. The objectives of this research were to provide design criteria for the incorporation of HRAPs into CWMS and insight into the optimum depth and THRT for HRAP wastewater treatment performance and algal biomass production across seasons.

2. Material and methods

2.1. HRAP design and operation

The HRAP was constructed at the Kingston on Murray (KoM; population equivalent 300) wastewater treatment site (34°14′34.1″S 140°19′48.7″E) in 2008. The HRAP was a single loop raceway (length 30 m, single channel width 2.5 m) lined with a high-density polyethylene sheet, from which the floating dividing wall between the channels was also constructed. Water was circulated continuously at a mean surface velocity of $0.2\,m\,s^{-1}$ by an 8 blade, stainless steel paddlewheel wheel driven by a 0.75 kW electric motor. Water depth within the HRAP was controlled by adjusting the height of the vertical overflow pipe. The performance of the HRAP was evaluated at 3 depths, 0.32 m (shallow), 0.43 m (medium) and 0.55 m (deep). The THRT of the HRAP co-varied with depth and was 4.5 days (shallow), 6.4 days (medium) and 9.1 days (high). To avoid confusion, the results are described in terms of depth related influences since the practical necessity to treat wastewater at constant flow precluded maintaining THRT when operational depth was changed. Since the rammed earth walls were necessarily sloped, the effective surface area of the HRAP also varied slightly with depth – from $192\,m^2$ (shallow), $208\,m^2$ (medium) to $226\,m^2$ (deep).

The performance of the HRAP was evaluated using two different influent sources. Residential properties within Kingston on Murray retain their on-site septic tanks (minimum retention time 24 h), the overflow from which was reticulated to the wastewater treatment plant operated by Loxton Waikerie District Council. In the first evaluation of performance, the HRAP was fed this wastewater ($12\,m^3\,day^{-1}$) and operated from 1 May 2010 to 16 April 2011.

A waste stabilisation pond system was also constructed at Kingston on Murray in 2008 to treat septic tank effluent. This comprised of a facultative lagoon (1, 800 m^2, depth 1.2 m) followed by 4 maturation ponds (each 375 m^2, depth 1.2 m) operated in series. In the second performance evaluation, the reticulated septic tank effluent was pre-treated in the facultative pond (THRT 30 days), and the effluent from this pond was fed to the HRAP. This evaluation was conducted from 18 July 2011 to 21 January 2012.

2.2. Monitoring and analysis

2.2.1. Climate monitoring

The site was equipped with a weather station (Environdata 3000 Weather Station, Environdata, Queensland) which continuously logged total solar radiation and total UV irradiation (290–400 nm), air temperature, rainfall, humidity, wind speed and direction.

2.2.2. Continuous pond monitoring

The wastewater in the HRAP was continuously monitored *in situ* for temperature (thermistor accuracy ± 0.2 °C; T-Tec, South Australia), pH and dissolved oxygen (DO) using a probe and membrane electrode respectively (4600 series transmitter, ABB Ltd., Australia) and the data logged continuously. The probes were located, for all three operational depths, upstream of the paddlewheel, 0.2 m below the surface. The probes were cleaned and calibrated routinely (approximately every 14 days); using commercially sourced buffer solutions (pH 7.0 and 10, LabServ™, Thermo Fisher Scientific, Australia); DO air calibration (100%) and saturated sodium sulphite (0%) according to manufacturer's instructions,

2.2.3. Wastewater sampling and analysis

Samples of wastewater influent to the HRAP were collected directly from the inlet pipe either during influent pumping or immediately after pumping had ceased. Treated HRAP effluent wastewater was collected using a refrigerated (1 °C) auto-sampler (Avalanche Sampler, ISCO Ltd., USA) from the outlet standpipe of the HRAP. Samples were collected and transferred to a car refrigerator (1 °C) for transport to the laboratory and analysed within 24 h of collection. Following a change in operational depth, sampling of the HRAP commenced, after the equivalent of three THRTs had elapsed to enable the establishment of steady-state conditions. The HRAP was then sampled for a minimum of a further three THRTs.

Influent and effluent wastewater samples were analysed using the methods described in *Standard Methods for the Examination of Water and Wastewater* [20]. The particular test versions used were for turbidity (NTU; Method 2130 B: p 2–9), suspended solids (SS; Method 2450 D p 2–56), chlorophyll *a* (Chl*a*; Method 10200 (Chlorophyll – trichromatic method) on pages 10–18/19), BOD_5 (Method 5210 B: pp 5–2 to 5–6), and the nutrients NH_4-N (Method 4500-NH_3 H: p 4–84), NO_2-N (Method 4500 NO_2^- B: p 4–85), NO_3-N (Method 4500-NO_3^- F: p 4–91) and PO_4-P (Method 4500-P D: p 4–115). Electrical conductivity was measured using a portable conductivity meter (Jenway, UK, Model 470). *E. coli* $100\,mL^{-1}$ was enumerated using the Colilert™ (Idexx Ltd.) most probable number (MPN) chromogenic substrate assay.

2.2.4. Data analysis

E. coli removal rates are reported as $\log_{10}$ reduction values (LRVs) calculated by subtracting the outlet value (*E. coli* $\log_{10}$ MPN $100\,mL^{-1}$) from the inlet value (*E. coli* $\log_{10}$ MPN $100\,mL^{-1}$) on each day of sampling. The LRV is a parameter included in World Health Organization Guidelines [21–23] considering the management of microbial risk to public health associated with the use of wastewater, excreta and greywater by agriculture and aquaculture. This parameter has also been adopted by Australian State Health Departments for licencing wastewater treatment plants. Removal efficiencies of BOD_5 and nutrients were calculated using Eq. (1)

$$\frac{C_0 - C_e}{C_0} \tag{1}$$

where, C_0 = inlet concentration ($mg\,L^{-1}$) and C_e = outlet concentration ($mg\,L^{-1}$).

Suspended solids productivity ($g\,m^{-2}\,day^{-1}$) was derived by the product of total suspended solids and daily effluent outflow, divided by