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The effect of aerated rock filter geometry on the rate of nitrogen removal from facultative pond effluents

R. Hamdan[1,2] and D. D. Mara[1]

[1] School of Civil Engineering, University of Leeds, Leeds LS2 9JT, UK
(E-mail: *cnrh@leeds.ac.uk* and *d.d.mara@leeds.ac.uk*)
[2] University Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
(E-mail: *rafidahh@uthm.edu.my*)

Abstract
Rock Filters are an established technology for polishing waste stabilization pond effluents. However, they rapidly become anoxic and consequently do not remove ammonium-nitrogen. Horizontal-flow aerated rock filters (HFARF), developed to permit nitrification and hence ammonium-N removal, were compared with a novel vertical-flow aerated rock filter (VFARF). There were no differences in the removals of BOD_5, TSS and TKN, but the VFARF consistently produced effluents with lower ammonium-N concentrations (<0.3 mg N/L) than the HFARF (0.8−1.5 mg N/L).

Keywords
Aerated rock filters; ammonium nitrogen; facultative ponds; horizontal flow; vertical flow

INTRODUCTION

Rock filters (RF) are a well-established technology for ‘polishing’ maturation pond effluents to provide high-quality effluents in terms of BOD and total suspended solids (TSS) (O’Brien et al., 1973; Martin and Weller, 1973; Swanson and Williamson, 1980; Middlebrooks, 1988, 1995; Saidam et al., 1995; Neder et al., 2002; US EPA, 2002). However, these RF rapidly become anoxic and there is no (or very little) removal of ammonia. To remove ammonia the RF must be aerated and it is better to treat facultative (rather than maturation) pond effluents in aerated RF so as to remove the need for maturation ponds and thus save land; aeration also improves BOD and TSS removals (Johnson 2005; Mara and Johnson and Mara 2006). Johnson and Mara (2007) found that an aerated RF outperformed an unaerated subsurface horizontal-flow constructed wetland (SSHF-CW) and Mara (2006) showed that the combination of a primary facultative pond and an aerated RF produced a better quality effluent, required less land, and was cheaper, than a septic tank and SSHF-CW. [Aeration has also been proposed for SSHF-CW by Davies and Hart (1990), Cottingham et al. (1999), Maltais-Landry et al. (2007) and Ouellet-Plamondon et al. (2007).]

In this paper we report results obtained from two pilot-scale aerated RF of very different geometries. Both received the same volumetric hydraulic loading and air flow rates, but one had a depth of 0.5 m (as in the original work by Johnson, 2005) and the other a depth of 2 m.

MATERIALS AND METHODS

Pilot-scale units

The facultative pond was loaded at 80 kg BOD/ha day (Abis and Mara, 2003) using a variable-speed peristaltic pump (Watson Marlow model 505S pump fitted with a model 501RL pump head). A vertical-flow aerated RF (VFARF) and a horizontal-flow aerated RF (HFARF) were operated in parallel at our experimental station at Yorkshire Water’s Wastewater Treatment Works at Esholt, Bradford. The dimensions and operating conditions of the two RF are given in Table 1 and they are shown in Figures 1 and 2.

The rock filters were filled with 40–100 mm limestone aggregate and aerated using an oil-free Jun-air compressor (model OF302-25B) at an air flow rate of 20 L/min. The 12-mm reinforced plastic pipework, used to convey the facultative pond effluent to the RF, was heated during winter using a T-type thermocouple (model DTC 410 with temperature control) and a heating cable (Flexelec model FTP). A flow meter was installed at the inlet of the VFARF to monitor the flow to it and airflow meters were installed for both RF. The RF effluents were discharged by gravity to the nearest drain.

Table 1. Dimensions and operating conditions of the aerated RF

Parameter	VFARF	HFARF
Height (m)	2.0	0.5
Width (m)	−	0.5
Length (m)	−	4.0
Internal diameter (m)	0.3	−
Filter bed depth/ Liquid depth (m)	1.8 / 1.5	0.6 / 0.5
Rock volume (m^3)	0.12	1
Wastewater flow (ml/min)	50	420
Velocity (m/s)	1.18×10^{-5}	2.8×10^{-5}
Hydraulic retention time (d)	1.6	1.6
Hydraulic loading rate (m^3/m^3 d)	0.6	0.6
Airflow rate (L/min)	20	20
Sampling points (m below surface)	0.25, 0.5, 0.75, 1.0,1.25, 1.5	−

Figure 1. The HFARF (unit on the right).

Figure 2. The VFARF.

Wastewater sampling and analysis

Grab samples of the influent and effluent of the two RF were collected and analysed weekly, following *Standard Methods* (APHA, 1998), for BOD (method no. 5210 B), ammonia (4500-NH_3 D), TKN (4500-N_{org} C) and TSS (2540 D). Dissolved oxygen (DO), pH, and temperature were measured in situ using a sonde probe (YSI model 610-DM), and nitrate was analysed weekly by an ion analyser (DIONEX model DX500). All laboratory analyses were conducted in the Public

Health Engineering Laboratories, School of Civil Engineering, University of Leeds (16 km from Esholt).

RESULTS AND DISCUSSION

BOD_5 removal

Generally BOD_5 removal was slightly higher in the VFARF than in the HFARF. The BOD_5 removal efficiency of the VFARF varied from 67 to 90% and in the HFARF from 48 to 84%. As shown in Figure 3, the BOD_5 concentration in the RF influents was in the range 21–80 mg/L; in the VFARF effluent it was 7−9 mg/L and in the HFARF effluent 9−14 mg/L (these effluent ranges are not significantly different − student *t* test: $p = 0.14$). Both effluents complied with the BOD_5 requirements of the EU Urban Waste Water Treatment Directive (UWWTD) (Council of the European Communities, 1991).

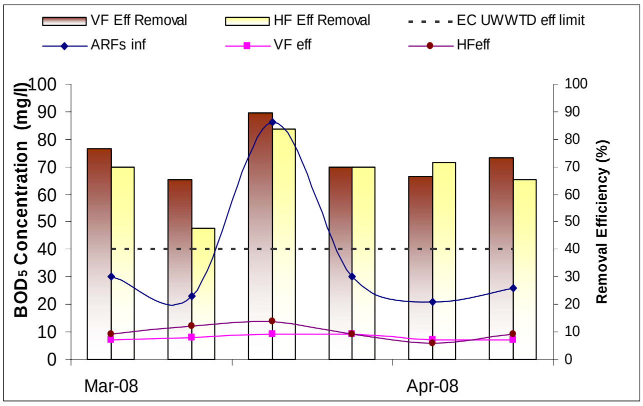

Figure 3. VFARF and HFARF influent and effluent BOD_5 concentrations and removal efficiencies.

TSS removal

Figure 4 shows that the HFARF performed slightly better than the VFARF but the effluent TSS concentrations were not significantly different (*t* test: $p = 0.37$); both complied with the requirements of the UWWTD.

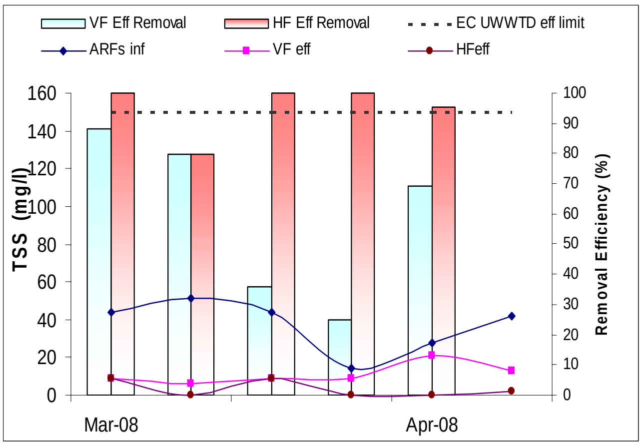

Figure 4. VFARF and HFARF influent and effluent TSS concentrations and removal efficiencies.

Nitrogen removal

Ammonium. Influent ammonium-N concentrations ranged from 4 to 11 mg NH_3-N/L during this monitoring period. The VFARF performed much better than the HFARF system: the NH_3-N concentrations in the VFARF effluent were consistently <0.3 mg/L, whereas in the HFARF effluent they ranged from 0.8 to 1.5 mg/L; removal efficiencies were significantly higher in the VFARF (94−100%) than in the HFARF (77−89%) (t test: $p = 0.001$), as were the effluent nitrate concentrations (Figure 5).

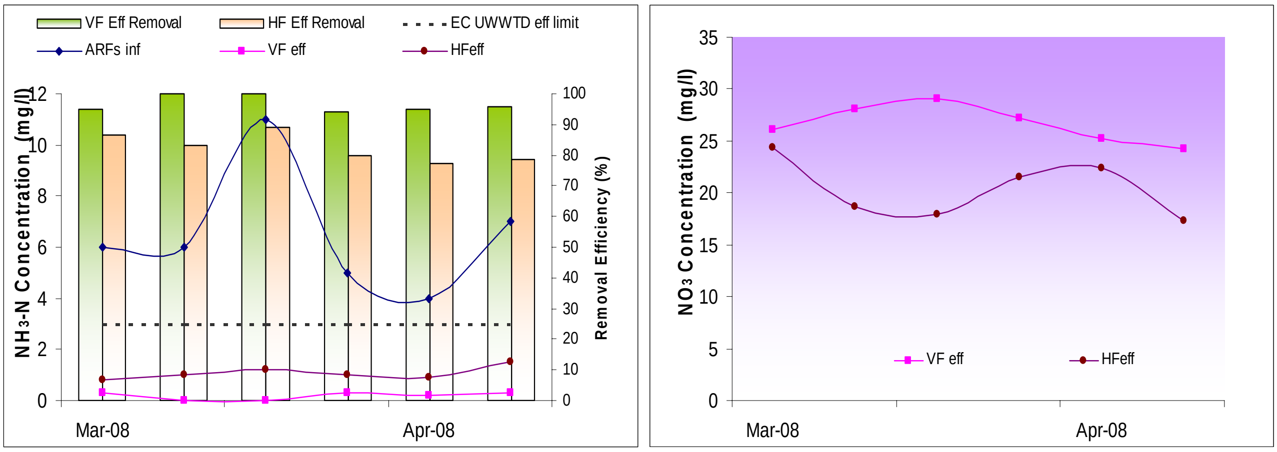

Figure 5. VFARF and HFARF influent and effluent NH_3-N concentrations and removal efficiencies (left), and nitrate concentrations in VFARF and HFARF effluents (right).

Total Kjeldahl nitrogen. The concentrations of TKN in the influent of VFARF and HFARF ranged from 12 to 19 mg/L NH_3-N/L. The TKN removal efficiency in the VFARF was ~99% but less in the HFARF (79−86%), although there was no significant difference between these values (t test: $p = 0.021$).

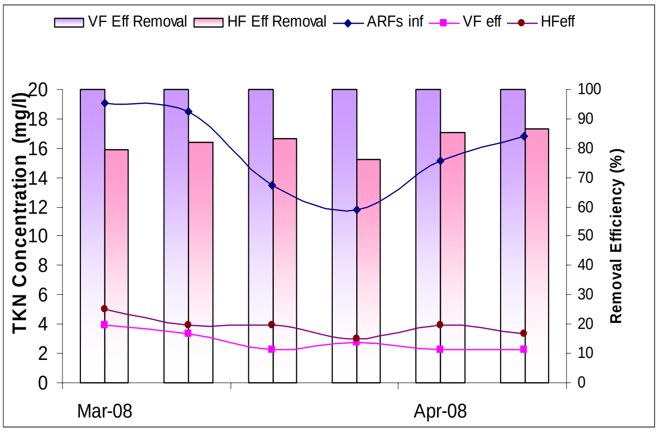

Figure 6. VFARF and HFARF influent and effluent TKN concentrations and removal efficiencies

CONCLUSION

The VFARF achieved a higher ammonium-N removal efficiency than the HFVRF. It requires less land than the latter and thus should be investigated further to optimize its design.

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