Wastewater treatment and algal production in high rate algal ponds with carbon dioxide addition

J. B. K. Park*, R. J. Craggs

National Institute of Water and Atmospheric Research Ltd (NIWA), P. O. Box 11-115, Hamilton, New Zealand. (E-mail*: j.park@niwa.co.nz*)

Abstract High rate algal ponds (HRAPs) provide improved wastewater treatment over conventional wastewater stabilization ponds, however, algal production and recovery of wastewater nutrients as algal biomass is limited by the low carbon:nitrogen ratio of wastewater. This paper investigates the influence of CO_2 addition (to augment daytime carbon availability) on wastewater treatment performance and algal production of two pilot-scale HRAPs operated with different hydraulic retention times (4 and 8 days) over a New Zealand Summer (November – March, 07/08). Weekly measurements were made of influent and effluent flow rate and water qualities, algal and bacterial biomass production, and the percentage of algae biomass harvested in gravity settling units. This research shows that CO_2 addition to the HRAPs treating wastewater enhanced algal production (maximum algae productivity: 24.7 $g/m^2/d$ measured in January 08, mean algal productivity: 16.7 $g/m^2/d$ for the $HRAP_w$ (4 d HRT) and 9.0 $g/m^2/d$ for the $HRAP_E$ (8 d HRT)). Algae biomass produced in the HRAPs was efficiently harvested by gravity settling units (mean harvested algal productivity: 11.5 $g/m^2/d$ for the $HRAP_w$ and 7.5 $g/m^2/d$ for the $HRAP_E$ respectively). Higher bacterial composition and bioflocculation of the $HRAP_E$ biomass increased harvestability (83%) compared to that of $HRAP_W$ biomass (69%).

Keywords Algae; CO_2 addition; algae harvest; high rate algae ponds (HRAP); algae production

INTRODUCTION

High rate algal ponds (HRAPs) provide improved wastewater treatment over conventional wastewater stabilization ponds (WSPs) through algal growth and photosynthetic oxygen production for bacterial degradation of BOD (Oron, 1979; Oswald, 1991; Green, 1995; Pagand, 2000; Craggs, 2002). The carbon:nitrogen ratio of wastewater (typically 7C:N) is low compared to that of algal biomass (typically 15C:N), therefore algal production and recovery of wastewater nutrients as algal biomass in HRAP could be enhanced by CO_2 addition . Controlling pond water pH to below 8 with CO_2 addition may also enhance algal production by preventing ammonia inhibition of algal growth (Bush, 1961; Azov, 1982a). For example, when the pH rises to 9.5 (20-25°C) total free ammonia concentration of only 34 and 51 g/m^3 will lead to 50 and 90% reductions in photosynthesis respectively of freshwater algae such as *Scenedesmus obliquus* (Azov, 1982b). Moreover, aerobic heterotrophic bacteria which use photosynthetically derived oxygen to breakdown dissolved organic compounds (BOD removal) and release CO_2 and nutrients (N and P) have an optimum pH of 8.3 above which bacterial activity is increasingly inhibited (Oswald, 1957; Oswald, 1960; Oswald, 1988). However, controlling HRAP pH to below 8 will reduce nutrient removal by physico-chemical processes such as ammonia volatilisation and phosphate precipitation occurring at pH >9, which could reduce overall nutrient removal unless offset by increased algal assimilation.

There is little information in the literature on CO_2 addition to wastewater treatment HRAPs and the influence on treatment performance and algae production. Laboratory scale research on CO_2 addition to wastewater grown algae cultures has demonstrated higher algal photosynthetic efficiencies and productivities compared to controls without CO_2 addition (Oswald, 1960; Fitzgerald, 1964; Ha, 2005; Heubeck, 2007). Bush *et al.* (1961) concluded that maximum algal productivity in an experimental outside algae wastewater pond could only be achieved if additional CO_2 was added. Moreover, Azov *et al.* (1982b) found that CO_2 addition to a pilot-scale nutrient media high rate algae pond more than doubled algal production compared to a control pond without CO_2 addition. Several devices have been developed for CO_2 addition to HRAP including: a pressurised floating CO_2 cushion (Bush, 1961; Heussler, 1978) a counter current tower (Benemann, 2003), and a counter current pit (Mandeno, 2003).

This research builds on our previous laboratory-scale research on CO_2 addition to wastewater grown algal cultures (Heubeck, 2007) by investigating the influence of CO_2 addition (to augment carbon availability) on wastewater treatment performance and algal production of two pilot-scale HRAPs operated with different hydraulic retention times (4 and 8 days) and concentrations of influent organic matter and nutrients, but the same organic and nutrient loading over a New Zealand Summer (November - March, 07/08).

MATERIALS AND METHODS

Experimental pilot-scale HRAP system

Experiments were conducted using two identical pilot-scale HRAPs (West and East), which were a part of an Advanced Pond System (APS) treating domestic wastewater at the Ruakura Research Centre, Hamilton, New Zealand (37°47’S, 175°19’E). Each HRAP was a single-loop raceway (surface area: 31.8 m^2, depth: 0.3 m, volume: 8 m^3) with semi-circular end-walls; lined with high-density polyethylene (HDPE) plastic; and with a dividing wall (HDPE) separating the two raceway channels. A free standing, 1 m wide, galvanised steel paddlewheel circulated the pond water around the HRAP raceway to give mean surface velocity of 0.15 m/s. The HRAPs each received anaerobic digester effluent (1 m^3/d) which was added at the pond bottom downstream of the paddlewheel. The influent to the West HRAP was diluted with 1 m^3/d of tap water to give hydraulic retention times of 4 day and 8 days respectively for the West and East HRAP ($HRAP_W$, $HRAP_E$). Effluent from the HRAPs was taken from the pond bottom upstream of the paddlewheel to ensure complete mixing within the HRAP.

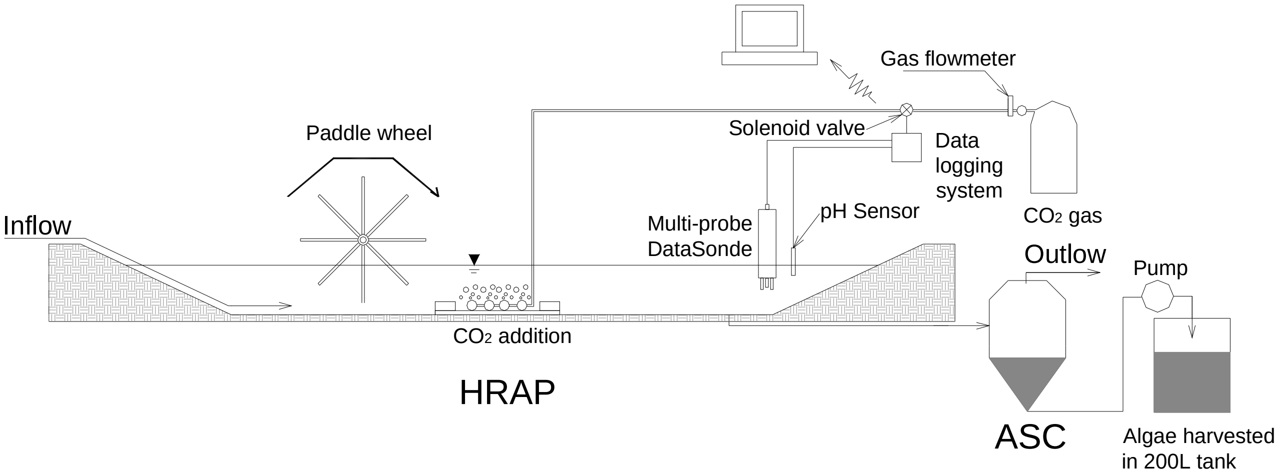

Figure 1. Schematic diagram of the pilot-scale high rate algae pond (HRAP) equipped with a CO_2 addition system to maintain the maximum pond water pH below 8, a multi-probe DataSonde for pH, DO, and temperature measurement, a data logging system for data acquisition. Algae settling cones (ASCs) for algae biomass harvest from the HRAP.

CO_2 addition

The maximum pH of the HRAPs was maintained below 8 through pH controlled addition of CO_2. The CO_2 addition system consisted of a CO_2 gas cylinder (BOC Gas Ltd, N.Z), a CO_2 gas regulator, a gas flow metre (0-12 litre range), a solenoid valve and gas diffusers. Pond water pH was measured every five seconds with a pH probe and when the pH exceeded the pH 8 set point, the controller opened the solenoid valve and bubbled CO_2 into the ponds (2 L/min) through two CO_2 gas diffusers placed on the pond bottom in turbulent zones (one just before the paddlewheel and the other at the pond corner). When the pond water pH reduced to pH 7.8 the controller closed the solenoid valve halting CO_2 addition. The pH probes were calibrated 1-2 times a week with standard pH solution (pH 7 and 10).

Algae harvest

Gravity algal settling cones (ASCs, 250 L each) were used to harvest the algal biomass grown in the HRAPs. Effluent from each HRAP was divided between two ASCs and introduced horizontally into each cone at mid-depth. ASC effluent overflowed from the top of the cones while settled algal biomass collected at the bottom and was continuously removed using a peristaltic pump (Masterflex, Cole-Parmer, HV-07523-60). The harvested algal biomass was stored into a 200 litre tank and 2-3 times a week, the total volume harvested was determined and a sample was taken to measure TSS/VSS.

Monitoring

Pond water physical properties (pH, DO and temperature) were continually measured using a DataSonde® 4a (Hydrolab, HACH Environment, USA) and data was logged at 15 minute intervals using a datalogger (CR10X, Campbell Scientific Inc, UT, USA) that downloaded daily through a wireless modem. HRAP inflow was measured by tipping buckets and data was also logged at 15 minute intervals using the datalogger. The Datasonde pH and DO probes were calibrated every week following manufacturer's procedures.

Weekly samples of effluent from the digester (influent), HRAPs and ASCs were taken using composite autosamplers, sampling at an hourly intervals over 24 hours. These samples were then analysed using standard methods (APHA, 2000) for the following parameters: total suspended solids (TSS), volatile suspended solids (VSS), total and soluble 5-day biochemical oxygen demand ($TBOD_5$, $SBOD_5$), and chlorophyll-*a* (Chl-*a*). TKN, ammoniacal-N (NH_4^+-N), total phosphorus (TP), dissolved reactive phosphorus (DRP) were also measured but will be reported elsewhere. Algae biomass was estimated from the chlorophyll-*a* concentration, assuming that 1.5% of algae biomass is Chl-*a* (Raschke, 1993):

$$[\text{Algae biomass (mg/L)}] = [\text{chlorophyll-}a\text{ (mg/L)}] \times 100/1.5 \qquad (1)$$

RESULTS AND DISCUSSIONS

The influence of CO_2 addition (to augment carbon availability) on algal production and wastewater treatment performance of two pilot-scale HRAPs operated with different hydraulic retention times ($HRAP_W$: 4 d and $HRAP_E$: 8 d) and concentrations of influent organic matter and nutrients, but the same organic and nutrient loading was measured over a New Zealand summer (5 months, November - March, 07/08). The HRAPs were continuously operated with CO_2 addition to maintain maximum pond water pH below pH 8 and the influent to $HRAP_W$ was diluted 1:1 with tap water to reduce the HRT from 8 to 4 days. Both HRAPs were monitored at weekly intervals to compare performance of algae production and wastewater treatment.

pH control and physical characteristics of HRAPs

Temperature, DO and pH of both HRAPs were continuously monitored over the experimental period and data are summarized in Table 1. Median water temperature of both HRAPs increased from 18.5 to 23.5°C between November 2007 and January 2008 and then declined to 19.6°C by March 2008. The maximum D.O levels for both HRAPs exceeded 100% saturation throughout the experimental period and both HRAPs remained aerobic at night as indicated by the minimum night-time DO% saturation ($HRAP_E$: 5.5 - 12.7%, and $HRAP_W$: 1.8 - 8.1%). It indicated that sufficient algal photosynthesis occurred in both ponds despite the different HRT. CO_2 addition effectively controlled maximum pond water daytime pH to 8 in both ponds (Table 1 and Figure 2), however, one consequence was the lowering of the night-time pond pH minimum to as low as pH 6.2. Hence the overall pH range 7.9 - 6.2 of HRAP with CO_2 addition was shifted down when compared with that (pH 10.2 to 7.2) of HRAP without CO_2 addition (Heubeck, 2007). March 2008 data for pond water pH variation and volumetric CO_2 addition rates are shown in Figure 2 as an example. The wide variation in CO_2 addition over time and between the ponds was probably a result of variation in algal photosynthesis with variation in climate, total algal concentration, and variation in bacterial degradation of organic matter.

Table 1. Water temperature, DO and pH of two pilot-scale HRAPs with CO_2 addition ($HRAP_E$: 8 d HRT; $HRAP_W$: 4 d HRT)

$HRAP_E$	Temperature (°C)		DO (% Saturation)		pH	
Month	Median±s.d.	Max/Min	Median±s.d.	Max/Min	Median±s.d.	Max/Min
Nov 07	18.5±2.2	22.2/15.4	50.5±49.1	138.1/ 0.8	7.62±0.33	7.92/7.34
Dec 07	21.5±2.1	24.8/18.4	53.7±78.0	222.4/ 5.5	7.23±0.29	7.78/6.89
Jan 08	23.5±2.3	27.5/20.0	99.9±114.2	351.3/ 6.9	6.90±0.45	7.94/6.45
Feb 08	20.3±2.2	25.0/17.9	46.2±54.0	162.3/ 9.4	7.40±0.29	7.95/6.66
Mar 08	19.6±1.7	23.3/16.2	76.6±89.3	267.7/12.7	7.03±0.26	7.40/6.54
$HRAP_W$	Temperature (°C)		DO (% Saturation)		pH	
Month	Median±s.d.	Max/Min	Median±s.d.	Max/Min	Median±s.d.	Max/Min
Nov 07	18.5±2.3	21.9/15.1	24.8±43.2	122.0/0.6	7.41±0.54	7.95/6.91
Dec 07	21.5±2.3	24.6/18.3	84.0±84.5	238.2/5.3	7.61±0.65	7.89/6.92
Jan 08	23.4±2.3	27.5/19.7	65.8±56.1	172.1/21.8	7.17±0.46	8.06/7.07
Feb 08	20.9±2.1	24.6/18.1	30.6±59.9	169.3/3.6	6.91±0.25	7.97/6.59
Mar 08	19.3±1.1	23.1/16.5	55.9±59.9	169.1/8.1	6.97±0.31	7.98/6.25

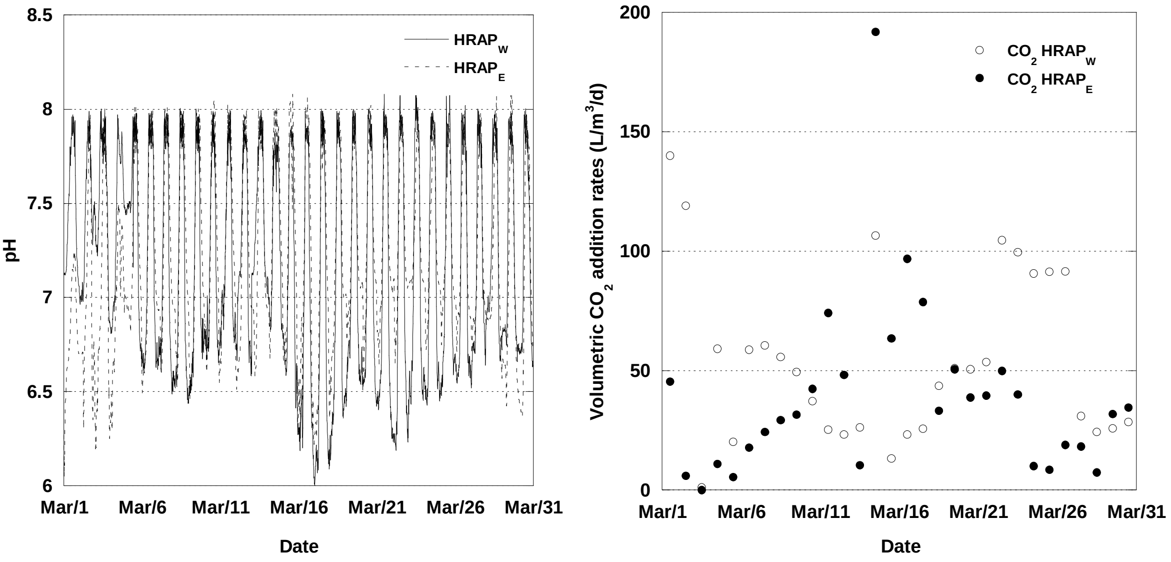

Figure 2. pH control and volumetric CO_2 addition rates for the HRAPs typically in March 2008

Organic compound removal

Influent and effluent median $TBOD_5$, $SBOD_5$, TSS, VSS and Chlorophyll-*a* concentrations, organic loading rates (as $SBOD_5$), removal rates and percent removal from both HRAPs are summarized in Table 2.

Table 2. Influent and effluent organic compound ($TBOD_5$ and $SBOD_5$), TSS/VSS and Chl-*a* concentrations, volumetric dissolved BOD_5 loading rates, removal rates and percent removal for the HRAPs and ASCs. Note: * 1 m^3 tap water dilution

	HRAP$_E$		ASC$_E$	Total removal (%)	ASC removal (%)	HRAP$_W$		ASC$_W$	Total removal (%)	ASC removal (%)
	Inf.	Eff.	Eff.			Inf.	Eff.	Eff.		
Ave inflow rate	0.81	0.81	0.81	-	-	0.77	1.77*	1.77	-	-
$TBOD_5$ (g/m^3)	272.8	217.7	61.2	77.6	71.9	272.8	134.9	56.9	79.1	57.8
$SBOD_5$ (g/m^3)	257.7	11.2	14.4	94.4	-28.6	257.7	10.9	13.4	94.8	-22.9
$SBOD_5$ loading rate (g /m^3/d)	26.0	1.1	1.5	95.6	-31.8	24.8	1.0	1.3	95.8	-29.0
TSS (g/m^3)	79.0	596.0	175.2	-121.8	70.6	79.0	373.0	119.5	-51.3	68.0
VSS (g/m^3)	76.0	470.0	156.1	-105.4	66.8	76.0	300.0	129.1	-69.9	57.0
%VSS	96.0	79.0	89.0	-	-	96.2	80.4	108.0	-	-
Chl-*a* (g/m^3)	-	4.2	1.7	-	59.5	-	3.7	1.1	-	70.3

The proportion of dissolved $SBOD_5$ in the inflow Total BOD_5 ranged between 84.9 and 94.5%, indicating that most of the inflow organic matter was readily biodegradable. The organic loading rates of each of the HRAPs were calculated based on the inflow concentrations, average inflow rate and the pond volume (8 m^3).

During the experiment period both HRAP had similar mean volumetric $SBOD_5$ loading rates (26.0 and 24.8 $g/m^3/d$ for the $HRAP_E$ and $HRAP_W$ respectively). Mean $SBOD_5$ removal rates were also similar (24.9 and 23.8 $g/m^3/d$ for the $HRAP_E$ and $HRAP_W$ respectively). HRT had little influence on $SBOD_5$ removal with both ponds achieving ~95% $SBOD_5$ reduction based on either concentration reduction or removal rate (Table 2). These high dissolved organic compound removal rates may indicate that CO_2 addition to HRAPs enhances aerobic heterotrophic bacterial degradation of organic matter by preventing high pH (>9) inhibition and ammonia toxicity (Oswald, 1957; Oswald, 1960; Oswald, 1988).

Algal productivity and harvestability

Mean VSS and algae biomass concentrations and areal algal productivity for the HRAPs, and areal harvested algal productivity for the algae settling cones (ASCs) are summarized in Table 3. Both HRAP effluents had high VSS concentrations (470 and 300 g/m^3 for the $HRAP_E$ and $HRAP_W$ respectively, Table 2) and the %VS was the similar (~80%). Algae biomass concentrations were derived from Equation 1. The proportion of algae in the algae/bacteria biomass of the $HRAP_E$ (55.6%) was appreciably lower than in the shorter HRT $HRAP_W$ (80.5%). The mean algal productivity in the $HRAP_E$ (9.0 $g/m^2/d$) was much lower than that of the $HRAP_W$ (16.7 $g/m^2/d$) and although maximum productivity (January 08) was much higher in both HRAP there was a similar difference in the performance of the two ponds (15.2 and 24.7 $g/m^2/d$ for the $HRAP_E$ and $HRAP_W$ respectively). These results suggest that for the summer conditions of this experiment, the shorter 4-day hydraulic retention time with CO_2 addition promoted nearly double the algal production with a greater proportion of algal biomass than the longer 8-day hydraulic retention time with CO_2 addition. The reduced algal productivity in the $HRAP_E$ may have been due to increased light shading by the higher bacterial solids concentration.

The biomass productivity (algae/bacteria biomass measured as VSS) of 20.7 $g/m^2/d$ in the $HRAP_W$ is high compares with values measured in previous HRAP research in New Zealand (Craggs, 2002; Heubeck, 2007) and the peak summer production (24.7 g $VSS/m^2/d$ and 30.8 g $TSS/m^2/d$ for the $HRAP_W$) is similar to annual maximum literature values (~30 $g/m^2/d$ measured as TSS, Welssmen and Goebe, 1987). These results suggest that CO_2 addition to HRAPs enhanced algae production by augmenting daytime carbon availability (Bush, 1961; Fitzgerald, 1964; Heubeck, 2007) and also by possibly preventing free ammonia inhibition (Azov 1982a)

Mean harvested algal productivity measured from the biomass collected in the algae settling cones (ASCs) is shown in Table 3. The harvested algal productivities for the $HRAP_E$ and $HRAP_W$ were 7.5 and 11.5 $g/m^2/d$ respectively, indicating that 83% and 69% algae biomass produced from both HRAPs was harvested using ASCs. This suggests that CO_2 addition to the HRAPs also improved algae biomass removal compared to that of our previous experiments without CO_2 addition and using algal settling ponds which had a longer retention time (2 days) than the ASC (6 hours) (~50% removal, Tanner et al., 2005). In particular, algae biomass produced in the $HRAP_E$ was more efficiently harvested (83%) than that produced in the $HRAP_W$ (69%), suggesting that CO_2 addition with long HRT (8d) may stimulate bio-flocculation between algae and bacteria as a result of the increased bacteria population (44.4% total biomass) in the pond water.

The dominant algal species present in both HRAP during this 5 month study included the colonial algae *Scenedesmus sp, Microactinium sp* and *Pediastrum sp*, and the single cell alga *Ankistrodesmus sp*. The stability of the HRAP algal population during this experiment may have been a result of the more consistent pond conditions as a result of CO_2 addition.

Table 3. Areal biomass and algal productivity of the HRAPs and harvested algal productivity of algae settling cones (ASCs) during the experiment periods.

Parameters	$HRAP_E$		$HRAP_W$	
	Mean	s.d.	Mean	s.d.
VSS (g VSS/m^3)	547.8	270.5	341.1	161.0
Algae biomass concentration (g algae/m^3)	304.5	133.5	274.4	114.5
Algae (%)	55.6	10.5	80.5	4.5
Biomass productivity (as VSSg/m^2/d)	15.8	4.2	20.7	5.8
Algal productivity (g/m^2/d)	9.0	4.3	16.7	7.1
Harvested algal productivity (g/m^2/d)	7.5	2.5	11.5	5.9

The removal of particulate organic compounds ($TBOD_5$ and VSS) in the ASCs (total volume of 0.5 m^3) is summarized in Table 4. Mean volumetric $TBOD_5$ and VSS loading rates in ASC_E were 352.1 and 717.5 g/m^3/d respectively, and 70.8% (253.2 g/m^3/d) of the $TBOD_5$ and 62.7% (465.1 g/m^3/d) of the VSS were removed, indicating that particulate organic compounds measured as $TBOD_5$ and VSS (mostly organic biomass) were efficiently removed by gravity sedimentation. Overall performance of organic compound removal in the ASC_E was slightly higher than that in the ASC_W (52% $TBOD_5$ and 56.9% VSS removal), which was probably due to the increased bioflocculation of in the $HRAP_E$ which had a higher proportion of bacterial biomass than the $HRAP_W$.

Table 4. $TBOD_5$ and VSS removal in the algae settling cones (ASCs: total volume of 0.5 m^3).

Parameters	ASC_E		ASC_W	
	Mean	s.d.	Mean	s.d.
$TBOD_5$ loading rate (g $TBOD_5$/m^3/d)	352.1	130.8	208.5	92.4
$TBOD_5$ removal rate (g $TBOD_5$/m^3/d)	253.2	103.7	121.2	90.6
$TBOD_5$ reduction (%)	70.8	5.3	52.0	22.9
VSS loading rate (g VSS/m^3/d)	717.5	421.3	522.8	246.7
VSS removal rate (g VSS /m^3/d)	465.1	305.8	324.9	266.4
VSS reduction (%)	62.7	13.8	56.9	25.1

CONCLUSIONS

The main conclusions of this study comparing algae productivity and wastewater treatment of two pilot-scale HRAPs with CO_2 addition but different hydraulic retention times are:

1. CO_2 addition effectively controlled pond water pH below 8, without affecting pond water daytime maximum D.O levels or nighttime maintenance of aerobic conditions.
2. Both HRAPs removed organic compounds up to 95% (measured as $SBOD_5$).
3. The mean areal biomass (algal/bacterial) productivity in the $HRAP_W$ (HRT: 4d) was 20.7 g/m^2/d, which was greater than that of the $HRAP_E$ (15.8 g/m^2/d, HRT: 8d).

4. The mean areal algal productivity in the $HRAP_W$ (HRT: 4d) was 16.7 $g/m^2/d$, which was nearly twice that of the $HRAP_E$ (9.0 $g/m^2/d$, HRT: 8d).
5. The maximum algal productivity achieved with CO_2 addition and 4 day HRT was 24.7 g $/m^2/d$ measured in January 08.
6. Algae biomass was efficiently harvested by a simple gravity harvester (ASCs), higher bacterial composition and bioflocculation of the $HRAP_E$ biomass increased harvestability (83%) compared with that of $HRAP_W$ biomass (69%).

REFERENCES

APHA, 2000. *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, Washington.

Azov, Y., 1982a. Effect of pH on Inorganic Carbon Uptake in Algal Cultures. *Applied and Environmental Microbiology*, 43(6), 1300-1306.

Azov, Y., Goldman, J. C., 1982b. Free Ammonia Inhibition of Algal Photosynthesis in Intensive cultures. *Applied and Environmental Microbiology*, 43(4), 735-739.

Benemann, J.R., Koopman, B.L., Weissman, J.C., Eisenberg, D.M., Oswald, W.J., 1978. *An integrated system for the conversion of solar energy with sewage-grown microalgae*, U.S. Dept. of Energy, SAN-003-4-2.

Benemann, J.R. (2003). "Biofixation of CO2 and greenhouse gas abatement with michroalgae - Technology roadmap". Prepared for the U.S. Department of energy National energy technology laboratory, No:7010000926

Bush, A.F., Isherwood, J. D. and Rodgi, S., 1961. Dissolved solids removal from waste water by algae. *Journal of the Sanitary Engineering Division - Proceedings of the American Society of Civil Engineers*, 87(SA3), 39 - 57.

Craggs, R.J., R. J. Davies - Colley, C. C. Tanner and J. P. Sukias., 2002. *Advanced Pond System: performance with High Rate Ponds of different depths and areas*, 5th international IWA specialist group conference on waste stabilisation ponds. New Zealand Water and Wastes Association, Sky City Hotel, Auckland, New Zealand.

Fitzgerald, G.P.a.G.A.R., 1964. Biological removal of nutrients from treated sewage: laboratory experiments. *Verhandlungen der Internationalen Vereinigung fuer theoretische und angewandte Limnologie XV*, 597 - 608.

Green, F.B., T. J. Lundquist and W. J. Oswald., 1995. Energetics of Advanced Integrated Wastewater Pond Systems. *Water Science and Technology*, 31(12), 9-20.

Ha, M.V., 2005. Nutrient removal from African catfish culture through microalgae production. Master of Science Thesis, Ghent University.

Heubeck, S., Craggs, R. J., Shilton, A., 2007. Influence of CO2 scrubbing from biogas on the treatment performance of a high rate algal pond. *Water Science and Technology.* , 55(11), 193.

Heussler, P., J. Castillo, F. Merino and V. Vasquez., 1978. Improvements in pond construction and CO2 supply for the mass production of microalgae. *Arch. Hydrobiol. Beih*, 11, 254-258.

Mandeno, G., 2003. Advanced Pond Systems: Wastewater Treatment Performance and Biogas Purification in a High Rate Algae Pond. Auckland, The University of Auckland.

Olguín, E.J., 2003. Phycoremediation: key issues for cost-effective nutrient removal processes *Biotechnology Advances* 22 (1-2), 81-91

Oron, G., Shelef, G., Levi, A., Meydan, A., Aov, Y., 1979. Algae/Bacteria Ratio in High-Rate Ponds Used for Waste Treatment. *Appl Environ Microbiol*, 38(4), 570-576.

Oswald, W.J., 1960. Light conversion efficiency of algae grown in sewage. *Journal of the Sanitary Engineering Division - Proceedings of the American Society of Civil Engineers*, 86(SA4), 71 - 95.

Oswald, W.J. (Editor), 1988. *Micro-algae and wastewater treatment*. Micro-algae Biotech. Cambridge University Press, Cambridge, pp 305-328.

Oswald, W.J., 1991. Introduction to Advanced Integrated Wastewater Ponding Systems. *Water Science and Technology*, 24(5), 1-7.

Oswald, W.J., H. B. Gotaas, C. G. Golueke and W. R. Kellen., 1957. Algae in waste treatment. *Sewage and Industrial Wastes* 29(4), 437 - 457.

Pagand, P., Blancheton, J, P., Lemoalle, J., Casellas, C, 2000. The use of high rate algal ponds for the treatment of marine effluent from a recirculating fish rearing system. *Aquaculture Research*, 31, 729.

Raschke, R.L., 1993. Diatom community response to phosphorous in the Everglades National Park USA. *Phycologia*, 32(1), 48-58.

Tanner, C.C., Craggs, R.J., Sukias, J.P.S., Park, J.B.K., 2005. Comparison of maturation ponds and constructed wetlands as the final stage of an advanced pond system. Water Science and Technology 51, 307-314.

Welssmen, J. *C.* Goebe, R P., 1987. Design and Analysis of Microalgal Open Pond Systems for the Purpose of Producing Fuels. A Subcontract Report, prepared for U.S. Department of Energy, Contract No. DE-AC02-83CH10093