Advanced techniques for the upgrading of waste stabilisation pond effluent: rock filtration; duckweed; and attached-growth media

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"*It is striking that engineers have largely shaped the character of modern waste treatment, and even today one finds few aquatic biologists participating in it. Since most waste-treatment schemes are extensions of natural eutrophic ecosystems, ecologically oriented aquatic biologists could make a significant contribution to technologies heretofore dominated by sanitary engineers.*"

W.S. Hillman and D.D. Culley Jr. (1978).

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Michael Douglas Short

Abstract

Waste Stabilisation Ponds (WSPs) are a relatively simplistic and non-intensive wastewater treatment technology; with various WSP configurations widely employed to treat a range of different wastewaters the world over. Whilst the advantages of WSP treatment are both numerous and well recognized, performance problems relating to the presence of occasionally large and unpredictable quantities of plankton (both algal and zooplankton) biomass in the final pond effluents have posed significant operational problems for WSP operators; with this suspended biomass representing the single biggest drawback associated with the technology. Research conducted during this project was concerned with assessing a selection of so-called ‘advanced’ in-pond treatment processes for the upgrading or polishing of a final WSP effluent. The particular research emphasis was on the removal of problematic algal and zooplankton biomass from WSP effluent prior to Dissolved Air Flotation/Filtration (DAF/F) treatment and wastewater reuse at the Bolivar Wastewater Treatment Plant (WWTP) north of Adelaide.

The *in situ* WSP upgrade systems assessed in this thesis were: the native floating plant ‘Duckweed’ (DW); ‘Rock Filters’ (RFs); and an artificial ‘Attached-Growth Media’ (AGM); all of which were assessed for their relative treatment efficacies parallel to a non-interventional ‘Open Pond’ (OP) system which served as an effective control. These performance comparisons were assessed on a pilot-scale using a custom made pilot treatment plant which was located at the Bolivar WWTP. Performance monitoring was periodically carried out over a 12 month period from July 2005–August 2006, with algal and zooplankton populations monitored in addition to the more conventional wastewater quality parameters.

Results from pilot plant investigations demonstrated that of the four pilot upgrade series, the RF and AGM systems displayed the greatest treatment potential in terms of both the magnitude and reliability of suspended solids, algal and zooplankton biomass removals. The DW system was also shown to be at least as effective and in some instances significantly more advanced than the uncovered OP system in terms of its ability to

significantly improve the final effluent quality of the Bolivar WSPs. Both the RF and AGM upgrades (and to a lesser degree also the DW system) were found to offer considerable potential for producing a higher quality WSP effluent for more efficient processing by the Bolivar DAF/F plant; although there were various operational advantages and disadvantages as well as varying capital establishment costs associated with each of the candidate technologies. This part of the research represented the first direct performance comparison between two popular pond upgrade technologies (i.e. RFs and DW) and also constituted the first assessment of a novel AGM for the upgrading of tertiary-level WSP effluent. In addition to this, results from ecological performance monitoring also provided the first detailed insights into algal and zooplankton population dynamics within these WSP upgrade environments.

In addition to these pilot-scale WSP upgrade performance investigations, another branch of the research project investigated additional research questions regarding the survival of algal cells within these pond upgrade environments. A series of laboratory experiments attempted to recreate the *in situ* conditions (in terms of light and oxygen availability) that might exist within the adopted upgrade environments. Using two common WSP algal species, long-term monitoring of the physiological status of phytoplankton cells during prolonged dark-exposure under conditions of reduced oxygen availability was performed in order to assess the likely effects of these particular environmental conditions on their survival potential *in situ*.

Results from these laboratory-based experiments showed that both algal species were capable of quickly adjusting their cellular metabolism in response to dark incubation. Results also showed that a reduced environmental oxygen concentration (25% of saturation) had no bearing on the ability of either *Chlorella* or *Chlamydomonas* species to withstand long-term dark-exposure; with both species retaining what was essentially full biological viability following up to two months of continuous dark-exposure. In an applied context, these results suggested that subjecting algal cells to conditions of simultaneous darkness and reduced oxygen availability would be expected to have no significant adverse effects on algal survivorship within an advanced in-pond upgrade system such as a duckweed-covered WSP, a rock filter or an AGM system.

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I was once quoted saying "*there's no aptitude without gratitude*"; so it's now time to kneel down and give thanks!

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Abbreviations and nomenclature

τ	calculated mean hydraulic residence time
τ_{th}	theoretical hydraulic residence time
ºC	degrees Celsius
μg	microgram
μl	microlitre
μm	micrometre
μM	micromolar
mM	millimolar
μmol	micromole
μS cm^{-1}	microsiemens per centimetre
χ^2	Kruskal–Wallis test statistic (Chi-square approximation)
ABS	absorbance
AGM	attached-growth media
AGWSP	attached-growth waste stabilisation pond
ANCOVA	analysis of covariance
ANOVA	analysis of variance
A.U.	arbitrary units
BOD_5	five day biochemical oxygen demand
Chl. *a*	chlorophyll *a*
CI	confidence interval
cm	centimetre
CO_2	carbon dioxide
COD	chemical oxygen demand
CV	coefficient of variation
CWM	community waste management
d	day
DAF/F	dissolved air flotation/filtration
DMSO	dimethyl sulfoxide
DO	dissolved oxygen
DOC	dissolved organic carbon
DIC	dissolved inorganic carbon
DW	pilot-scale duckweed pond

F	analysis of variance F ratio
FACScan	Becton Dickinson brand flow cytometer
FC	faecal coliforms
FCM	flow cytometry
FDA	fluorescein diacetate (diacetyl fluorescein)
FSC	forward-angle light scatter
F_0	minimum *in vivo* chlorophyll *a* (PS-II) fluorescence yield (relative units) induced by a weak initial probing flash in dark-adapted cells
F_m	maximum *in vivo* chlorophyll *a* (PS-II) fluorescence yield (relative units) induced by a weak initial probing flash in dark-adapted cells
g	gram
H'	Shannon diversity index
h	hour
ha	hectare
HDPE	high-density polyethylene
HRT	hydraulic residence time
HLR	hydraulic loading rate
INFL	pilot plant influent
IQR	interquartile data range
K_1	BOD_5 removal rate coefficient (per day)
kg	kilogram
L	litre
m	metre
MBL	Woods Hole algal culture medium
MJ	megajoule
ml	millilitre
mm	millimetre
mg	milligram
mA	milliamp
mW	milliwatt
MPN	most probable number of organisms
n	sample size
NH_4^+-N	ammonia nitrogen
nm	nanometre

NO_3^--N	nitrate nitrogen
NO_2^--N	nitrite nitrogen
OLR	organic loading rate
OP	pilot-scale open pond
NTU	nephelometric turbidity units
PAR	photosynthetically active radiation (400–700nm wavelength)
PFD	photon flux density (light intensity)
pg	picogram
pH	potential hydrogen
PI	propidium iodide
PO_4^{3-}-P	orthophosphate phosphorous
PS-I / PS-II	chlorophyll *a* Photosystems I and II
PVC	polyvinyl chloride
Q_{SC}	short-circuiting flow rate
r	Pearson's correlation coefficient
R	flow cytometer sample injection flow rate
RF	pilot-scale rock filter
ROS	reactive oxygen species
r_s	Spearman's rank correlation coefficient
RTD	residence time distribution
s	second
S1	FDA-negative 'non-viable' fluorescence state
S2	reduced 'compromised' FDA fluorescence state
S3	normal 'viable' FDA fluorescence state
S.D.	standard deviation
SS	suspended solids
SSC	side-angle light scatter
TOC	total organic carbon
TC	total carbon
UV	ultraviolet
V_d	dead volume
VSS	volatile suspended solids
WSP	waste stabilisation pond
WWTP	wastewater treatment plan