

THE PERFORMANCE OF A DEEP PRIMARY WASTE
STABILIZATION POND

BY

SINGARAYER PATHINATHER

The thesis submitted to the Civil Engineering
Department of the Faculty of Engineering - University
of Moratuwa, Sri Lanka,
 www.lib.mrt.ac.lk

For the degree of
Master of Philosophy
January 1989.

53865.

This Thesis is



Respectfully Dedicated to
THE PARENTS
www.lib.mrt.ac.lk

of the author.

Acknowledgements

The author wishes to express his deep gratitude to his supervisor Prof. D.S. Wijeyesekera, for his inspiring guidance, continuous encouragement and helpful suggestions during this investigation.

The assistance and valuable advice offered by Prof. D.C.H. Senarath, Prof. B.L. Tennakoon and other staff of the department of Civil Engineering of the University of Moratuwa, Prof. S.J. Arceivala and Prof.(Mrs.) P.J. Paulraj are gratefully acknowledged.

The author acknowledges the resources provided by the Vice Chancellor, Dean of the Faculty of Engineering and other officers of the University of Moratuwa, and financial assistance provided by the IHE(Delft, Netherlands) and the National Water Supply and Drainage Board of Sri Lanka for this study program. Thanks are also extended to all laboratory personnel especially of the environmental engineering laboratory for their co-operations during the experimental work. The author wishes to mention with gratitude the 12 weeks fellowship offered by the WHO, during which period he did extensive literature review at IIT Bombay and AIT Bangkok.

Thanks are also due to the department of Meteorology for supplying the relevant climatological data, Ms D. Rodrigo for typing the thesis and all colleagues and friends who helped in numerous ways during this investigation. Finally the author expresses his sincere and heartfelt gratitude to his wife for her moral and spiritual support during the period of study.

ABSTRACT

This thesis describes an investigation into the performance of a deep primary waste stabilization pond under warm climatic conditions. Wastewater treatment designers in developing countries are constantly faced with the problem of selecting a system that is both efficient and economic. The main objective of this study was to determine safe loading rate and retention time in a pond deeper than the ponds normally used in warm climates. A secondary objective was to study the effect of using a deep pond in conjunction with a secondary shallow pond.

A pilot-scale pond of 3.6m depth as primary pond and an oil drum of 199 l capacity as secondary shallow pond were used under field conditions for the experimental study. The performance was evaluated by measuring influent and effluent BOD, COD and TC along with the measurements of DO, temperature, and pH profiles. Experimental results have shown that the high loaded deep pond is effective in the removal of bacteria and organic matter. A linear regression equation has been obtained for BOD and COD of raw domestic wastewater in order to predict BOD from COD measurements. The straight line regression equations have also been obtained to predict BOD and COD areal removal rates, covering ranges of 575 to 1406kg BOD/ha.d and 1137 to 2912kg COD/ha.d.

Average climatological factors from records of a 25 year period were analysed and the permissible areal organic loading computed. From this analysis and the experimental results obtained, it was concluded that the maximum areal loading should be limited to 640kg BOD/ha.d (or about 1300kg COD/ha.d) with a minimum hydraulic retention time of 11 days. Experimental study also revealed that the combination of a deep pond followed by a secondary pond can produce a high quality effluent in terms of soluble organics and bacterial numbers. An empirical equation to


predict BOD removal efficiency when volumetric organic loading is known was developed by analysing the experimental results and data collected from several publications. Using this equation, a chart to select suitable pond depths for different loading rates has also been developed.


Beneficial and adverse effects of tropical climates on pond performance are identified and discussed. The areas which require further study and development are also identified and recommendations made for future investigations.



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

C O N T E N T S

Acknowledgements		i	
Abstract		ii	
List of Figures		vi	
List of Tables		viii	
List of Symbols		x	
CHAPTER	1.	INTRODUCTION	1
	1.1	General Considerations in wastewater treatment	1
	1.2	History, types and usage of waste stabilization ponds	4
	1.3	Scope of this research	8
	1.4	Arrangement of this thesis	9
 CHAPTER	2.	LITERATURE REVIEW AND THEORETICAL CONSIDERATIONS	10
	2.1	Reactions and interactions in waste stabilization ponds	10
	2.2	Hydraulic characteristics and reaction kinetics of ponds	23
	2.3	Factors affecting pond performance	33
CHAPTER	3.	MATERIALS AND METHODS	49
	3.1	Exprimental works and analyses	49
	3.2	Analyses using performance data pooled from publications and long term records of climatological factors	57

CHAPTER 4.	RESULTS	59
4.1	Relationship between BOD and COD	59
4.2	General Performance of the deep pond	62
4.3	Areal organic loading and removal rates	85
4.4	Volumetric organic loading and BOD removal efficiency	88
4.5	Pond depth, loading and BOD removal efficiency	88
4.6	Climatological factors and permissible areal loadings.	93
 CHAPTER 5.	DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS	101
5.1	Discussion	101
5.2	Conclusions and Recommendations	117
REFERENCES		120
APPENDIX A		131
APPENDIX B		150
APPENDIX C		153

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Figures

	<u>Title</u>	<u>Page</u>
2.1	Waste Stabilization processes.	12
2.2	F - Diagram.	25
2.3	C - Diagram.	26
3.1	Schematic of deep pond	50
3.1a	Secondary pond.	51
3.2	Photograph of Universal and Ruttner type samplers.	52
3.3	Photograph of Secchi disc.	52
3.4	Photograph of Solar meter and pocket-lux meter.	53
3.5	Photograph of the temporary bridge over the pond.	53
4.1	Relationship between BOD and COD of raw wastewater.	60
4.2	Relationship between BOD and COD for pond effluent.	61
4.3	Diurnal DO at surface (R2 1986-7-2/3)	69
4.4	Diurnal Temperature at surface (R2 1986-7-2/3)	70
4.5	Diurnal pH at surface (R2 . 1986-7-2/3)	71
4.6	Variation of DO with depth (R2 . 1986-6-17/18)	72
4.7	Variation of Temperature with depth (R2. 1986-6-17/18)	73
4.8	Variation of pH with depth (R2 . 1986-6-17/18)	74
4.9	Diurnal DO profile (R3 . 1986-12-18)	75
4.10	Diurnal Temperature profile (R3 1986-12-18)	76
4.11	Diurnal pH profile (R3 1986-12-18)	77
4.12	Diurnal suspended solids profile (R3 1986-12-18)	78
4.13	Diurnal COD _T profile (R3 1986-12-18)	79
4.14	Diurnal DO profile (R3 1987-1-7)	80

4.15	Diurnal Temperature profile (R3 1987-1-7)	81
4.16	Diurnal pH profile (R3 1987-1-7)	82
4.17	Diurnal COD _r profile (R3 1987-1-7)	83
4.18	Diurnal Suspended solids profile (R3 1987-1-7)	84
4.19	Relationship of organic loading and removal rates (BOD)	86
4.20	Relationship of organic loading and removal rates (COD)	87
4.21	Volumetric organic loading Vs efficiency	90
4.22	Depth Vs loading with efficiency	91
4.23	Rate of oxidation Vs Hydraulic retention time	92
4.24	Long term trend of sunshine hours, wind speed and rainfall.	97
4.25	Long term temperature and expected oxygen production	98
4.26	Diurnal solar radiation - Average of 10 measurements	99
4.27	Typical Diurnal light intensity variation	100
C-1	Anaerobic degradation of an organic waste. Data obtained by Andrews with a Batch reactor (ref. Eckenfelder 1980)	154
C-2	Mean percent total time sun is above the horizon at a specified Latitude (ref. Oswald and Gotaas 1957)	155

List of Tables

	<u>Title</u>	<u>Page</u>
4.1	Summary of deep pond loading and performance	63
4.2	Effect of Secondary pond on BOD removal (Run R2)	65
4.3	Effect of Secondary pond on COD removal (Run R2)	66
4.4	Bacterial removal in ponds- (Run R2)	67
4.5	Bacterial removal in deep pond- (Run R3)	68
4.6	Performance data pooled from publications	89
4.7	Light penetration and algal species	94
4.8	Expected total Solar radiation, incident light intensity and the maximum fraction of light utilization	95
4.9	Expected oxygen production and permissible areal loading	96
5.1	BOD removal at 636 kg/ha.d (A comparison)	103
A-1	Mean COD and BOD of (unfiltered) raw wastewater	132
A-2	Mean COD and BOD of (filtered) effluent from the pond.	133
A-3	Summary of experimental results on deep pond	134
A-4	Deep pond performance (BOD removal)	135
A-5	Deep pond performance (COD removal)	136
A-6	Predicted BOD removal efficiency Vs depth under different volumetric and areal organic loading	137
A-7	Climatological records (Station Ratmalana) Average for 25 year period	138

A-8	Sunshine hours record (Station Colombo) Average for 25 year period	139
A-9	Summary of climatic data during the period of experimental investigations (Station Ratmalana)	140
A-10	Solar radiation and Sunshine hours (Station Colombo)	141
A-11	Summary of 10 solar radiation intensity measurements made near the pond	142
A-12	Solar radiation and light intensities measured near the pond on 1987-11-10	143
A-13	Profile characteristics. Deep pond (Run R2) on 1986-6-17 at 14.00 hours and on 1986-6-18 at 5.00 hours	144
A-14	Profile characteristics. Secondary pond (Run R2) on 1986-6-17 at 14.00 hours and on 1986-6-18 at 5.00 hours	145
A-15	Diurnal Variations of temperature, pH and DO at surface of ponds (Run R2)	146
A-16	Profile characteristics. Deep pond (Run R3) on 1987-12-18	147
A-17	Profile characteristics. Deep pond (Run R3) on 1987-1-7	148
A-18	Typical characteristics of raw wastewater	149
B-1	Solar radiation on a horizontal surface at sea level	151
B-2	Bibliography	152

LIST OF SYMBOLS

A	Surface area
Ac	Acre
BOD	This refers to 5 day Biochemical Oxygen Demand at 20° C. For simplicity this is used throughout the report instead of
	20
	BOD ₅
BOD _u	Ultimate Biochemical Oxygen Demand
C	Concentration of tracer at any time
C ₀	Initial concentration of tracer
C _a , C _c	Concentration of algae
COD	Chemical Oxygen Demand
COD _T	Total Chemical Oxygen Demand
D	Coefficient of dispersion, time in days
DO	Dissolved Oxygen
d ₀	Depth
d	Depth, time in days
°C	Degree Celcius
°F	Degree Fahrenheit
E	Removal efficiency in percentage
E _s	Fraction of solar energy fixed in organic matter
ESBOD	Effluent Soluble Biochemical Oxygen Demand
ESCOD	Effluent Soluble Chemical Oxygen Demand
F	Efficiency of energy conversion
FC	Faecal Coliforms
FS	Faecal Streptococci
f	Maximum fraction of light utilized
H	Stored energy
h	Calorific value of algae, time in hours
ha	Hectare
I _d	Light intensity at depth d.
I _i	Incident light intensity
I _s	Saturation light intensity
ITBOD	Influent Total Biochemical Oxygen Demand.
ITCOD	Influent Total Chemical Oxygen Demand
k	Reaction rate constant for BOD
k _b	Reaction rate constant for Bacteria
k _s	Reaction rate constant for sludge
k _g	Kilogram



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.hb.mru.ac.lk

L	Length of travel path, organic loading
L _r	Load factor
L _v	Volumetric organic loading rate
L _t	BOD at any time t
L _o	Areal loading rate
L _r	Areal removal rate
l	Litre
lb	Pound
MJ	Mega Joules
M _r	Mass of tracer instantaneously dropped into the reactor.
m	Metre
mm	Millimetre
mg	Milligram
ml	Millilitre
mv	Millivolt
N	Number of organisms remaining
N _o	Number of organisms originally present
ORP	Oxidation Reduction Potential
OL	Organic Loading
P	Mass of oxygen produced per unit mass of algae.
Q	Rate of flow
Q _i	Inflow rate
Q _o	Outflow rate
Re	Reynolds number
r	Sky clearance factor
S	Solar radiation, concentration of pollutant
S _o	Influent concentration of pollutant
S _{av}	Average Solar radiation
S _{min}	Minimum solar radiation
S _{max}	Maximum solar radiation
SP	Secondary Pond
SS	Suspended Solids
T	Temperature, ambient mean monthly temperature
T _c	Temperature coefficient
T _o	Initial temperance
T _t	Surface temperature
T _s	Sludge temperature
TC	Total Coliforms



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

TOC	Total Organic Carbon
t	Retention time
\bar{t}	Theoretical retention time
U	Mean velocity
V	Volume, velocity
W	Width, Watts
Z	Depth
α	Specific light absorption coefficient
δ	Dispersion number
F(θ)	Fraction of material at the outlet as a function of dimensionless θ (ie time)
μg	Microgram
ν	Kinematic viscosity
θ	Temperature coefficient, retention time
θ_c	Mean retention time
θ_{pf}	Plug flow deviation
λ	Species constant
λ_0, λ_i	Areal organic loading rate
λ_r	Areal organic removal rate

