PERFORMANCE OF A HIGH LOADED DEEP PRIMARY WASTE STABILIZATION POND

by

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Introduction

A Waste Stabilization Pond is a manmade basin utilizing natural processes under partially controlled conditions for the reduction of Organic matter and the destruction of pathogenic micro-organisms in wastewater. The main advantage in the use of stabilization ponds is that, with low operational and maintenance costs, relatively high treatment efficiencies are attainable. They do not require sophisticated equipment for their operation and are able to absorb hydraulic and organic shock loads. But nature is slow, requiring long retention periods which in turn imply large land requirements (Arceivala 1986). Use of deep Waste Stabilization ponds will help to reduce the land area required.

Ponds receiving raw wastewaters are called Primary Waste Stabilization ponds and those receiving primary-treated or biologically-treated wastewaters are called Secondary Waste Stabilization ponds. The organic loading and the availability of dissolved oxygen (DO) establish the biochemical environment of a pond, which may be classified as Aerobic (where DO is available throughout the depth at all times), Anaerobic (which is devoid of DO throughout the depth at all times) and Facultative (which is aerobic at the top and Anaerobic at the bottom). Primary waste stabilization ponds rely on settlement and Anaerobic digestion at the bottom for the removal of settleable solids, while non-settleable solids are broken down by aerobic processes at the top. Oxygen produced by algal photosynthesis and relatively small amount of atmospheric oxygen absorbed through the surface are used for the aerobic processes. The relative depths of Aerobic and Anaerobic layers in a pond will depend on organic loading, temperature, time of the day and the degree of vertical mixing in the pond. The end products of Anaerobic activity of the bottom deposits will diffuse upwards and exert an additional oxygen demand in the Aerobic zone. When the total oxygen demand in the aerobic zone exceeds the amount of oxygen that can be made available from photosynthesis and the atmosphere, the entire pond will become Anaerobic. However, if the organic loading is not too high, the top layer of the pond is likely to become Aerobic again during the day time when algal photosynthesis reaches its peak. Facultative pond failure is considered to occur when the pond reverts to an Anaerobic state throughout the day at all depths. It is desirable to maintain an Aerobic environment near the surface of the pond in order to minimize odour problems

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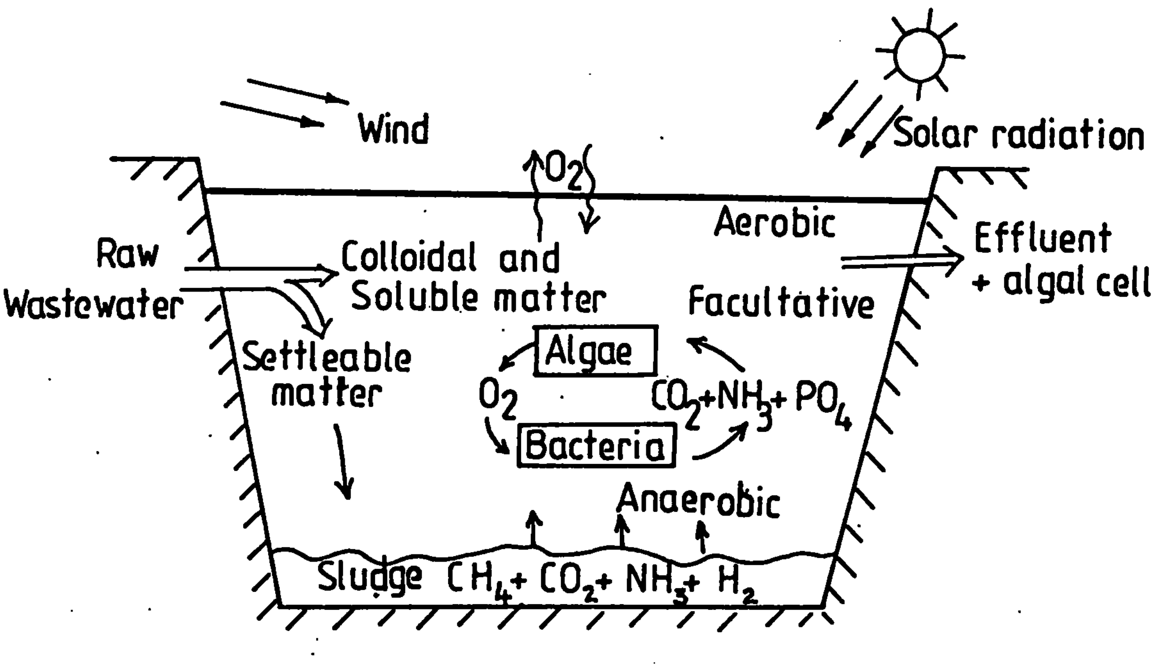

Fig. 1 Waste Stabilization Processes

and encourage Anaerobic decomposition at the bottom in order to reduce the major portion of the organic load.

Since pond performance is affected by environmental conditions such as temperature, solar radiation, rainfall, wind speed etc., data pertaining to the behaviour of deep ponds under the prevailing climatic and environmental conditions of the area becomes necessary for designing such ponds. One of the parameters used to evaluate pond performance is the biochemical oxygen, demand which measures the oxygen required to degrade a wastewater sample. An incubation period of 5 days at 20°C is commonly used but other lengths of time and temperature are also used. It is usual to quote the time and temperature in the results viz. BOD_5^{20} or BOD_3^{28}. International standard BOD_5^{20} is used in this work and for simplicity reference to BOD implies BOD_5^{20} in in this paper unless stated otherwise.

Since there are several limitations in the BOD test, numerous chemical methods have been devised to obtain the same type of results in a much shorter time. The most serious weakness of the BOD test is the fact that it indicates only a fraction of the total oxygen demand of the waste, which is not always constant.

The most widely used chemical oxidation procedure is the reflux method with acidified Potassium dichromate solution. This Chemical Oxygen Demand (COD), is also called Dichromate Value (DV), measures the amount of oxygen required for the chemical oxidation of the organic matter present in the waste. Most types of organic compounds are destroyed in this process (only aromatic hydrocarbons are not oxidized by this method). It is generally considered that COD gives an estimate of the entire organic matter present. However, this COD does not indicate the biologically oxidizable portion or the rate at which biologically active material would be stabilized under conditions that exist in nature. COD values of wastewaters are greater than BOD values and may be much greater when significant quantities of biologically resistant materials are present. A major advantage of the COD test is the short time (about 3 hours) required compared to 5 days in the case of the standard BOD test. For many types of wastes, it is possible to correlate COD with BOD and to use COD as a substitute in routine monitoring works after establishing reliable correlation factors.

Although waste stabilization ponds have been in use in many parts of the world from time immemorial, the engineered management of WSPS as a wastewater treatment began only 40 years ago. (Gloyna - 1971). Enormous volumes of literature published since its placement on a scientific basis, indicate that considerable research has been done on the various aspects of the waste stabilization ponds. However, little is known regarding the performance of deep primary waste stabilization ponds having depths considerably greater than those generally used, under tropical climatic conditions.

The objective of this paper is to discuss the performanc of a high loaded deep primary WSP and the correlation between COD and BOD of raw domestic wastewater and the pond effluent. The work described here is based on a research study conducted at the University of Moratuwa on a pilot scale deep primary waste stabilization pond.

Experimental Procedure

A pilot-scale pond of surface dimensions of 6m by 4m with side slope 1 in 8 and a liquid depth 3.6 m at mid area, constructed at the University of Moratuwa was used for this study. The pond has a total volume of 71.66 m^3 and a surface area of 19.7 m^2 at mid depth.

The pond was excavated in hard laterite soil and the sides of the pond were lined with 20 mm thick cement mortar in order to prevent excessive seepage. No attempt was made to artificially seal the bottom of the pond and it took nearly 2 months for bottom seepage to reduce to a negligible quantity. The pond received domestic wastewater originating from the residential halls of the University without any prior treatment. A portion of the wastewater from the main pipe was diverted and a control valve was used to regulate the feed in order to vary the hydraulic and organic loadings. Diverted flow was measured in a chamber installed with a coarse screen followed by a V-notch weir before being admitted to the pilot pond. Initially, rapid attainment of biological stabilization was encouraged by seeding the pond with decomposing cow dung.

For each run a period of twice the hydraulic retention time was allowed for stabilization. After reaching stabilization, flow-weighted composite samples of influent were collected and tested for COD (unfiltered) and BOD (unfiltered). Composite samples of effluent were also collected and tested for COD (filtered) and BOD (filtered). For the influent, 2 hourly samples were collected over a period of 24 hours and composited according to flow. In the case of the effluent 2 hourly samples were collected and composited in equal amounts. For each run samples were collected and tested once a week for a continuous period of 6 weeks. Efficiencies of COD and BOD removal were determined for 3 different loadings applied between February 1986 to January 1987. Grab samples of varying strength of the influent and effluent were used to test for COD and BOD in order to establish the correlation between these parameters. COD and BOD values obtained from grab samples were plotted statistically to obtain regression curves. The regression lines along with the equations and coefficients of correlation are shown in Figs. 2 and 3. Analytical methods used in this study are according to the procedure described in APHA - Standard Methods (1975).

Results & Discussion

Mean experimental observations (and range) obtained from three independent runs during the period February 1986 to January 1987 are presented in Table 1. Observations of total (unfiltered) COD and total (unfiltered) BOD for raw wastewater and soluble COD and soluble BOD of effluent are given in Tables 2 and 3 respectively.

Hydraulic retention times, organic loadings, BOD, COD removals and treatability indices obtained during one year of operation are summarised in Table 4.

COD - BOD Relationship and Treatability Index

Fig. 2 gives the plot of the total BOD Vs total COD of raw domestic wastewater. The least-squares regression equation for the line of best fit is

$$BOD = 0.483\ COD + 0.384 \qquad Se = \pm 11.95$$

Coeff. of correlation is 0.997 and coeff. determination is 0.994.

Fig. 3 gives the plot of the soluble BOD Vs soluble COD of the pond effluent. The least-squares regression equation for the line of best fit is

$$BOD = 0.383\ COD + 1.128 \qquad Se = \pm 8.92$$

Coeff. of correlation is 0.51 and coeff. of determination is 0.26.

The BOD/COD ratio of any waste will vary depending on the extent of its biodegradability, presence or absence of toxic materials and bactericides. When the character and composition of wastewater do not fluctuate very much, a good relationship between BOD and COD can be expected. The high correlation coefficient of 0.997 obtained for raw wastewater indicates greater reliability and also the presence of simple (easily biodegradable) organic matter. The correlation coefficient of 0.51 obtained for the effluent is poor and the plot exhibits great scatter of the BOD, COD data. The decrease in BOD/COD ratio indicates the increased concentration of the biochemically inert components in the effluent than in the raw wastewater. The poor correlation in effluent BOD/COD may also be due to the diurnal variation of the composition of the effluent, as grab samples were used for these tests. Therefore a relationship existing for raw wastewater does not hold good for treated wastewater. Moreover the correlation obtained for an effluent will be valid for a specific treatment process under specific loadings, climatic and other environmental conditions.

Reported BOD/COD ratio for domestic wastewater from other countries vary from 0.34 to 0.625 as follows:

Arceivala (1981)	0.53 to 0.625
Barnes' etal (1981)	0.5
Bulusu etal (1969)	0.34 to 0.48
Edwards & Sinchumpasak - (1980)	0.56

Biodegradability of a wastewater may be expressed in terms of "Treatability Index" (or TI) which can also serve as guide in the evaluation of the performance of biological treatment plants.

Bulusu etal (1969) Define Treatability Index

$$(TI)\ \text{as} = \frac{\text{Biodegradable matter}}{\text{Non-biodegradable matter}} = \frac{BOD}{COD - BOD}$$

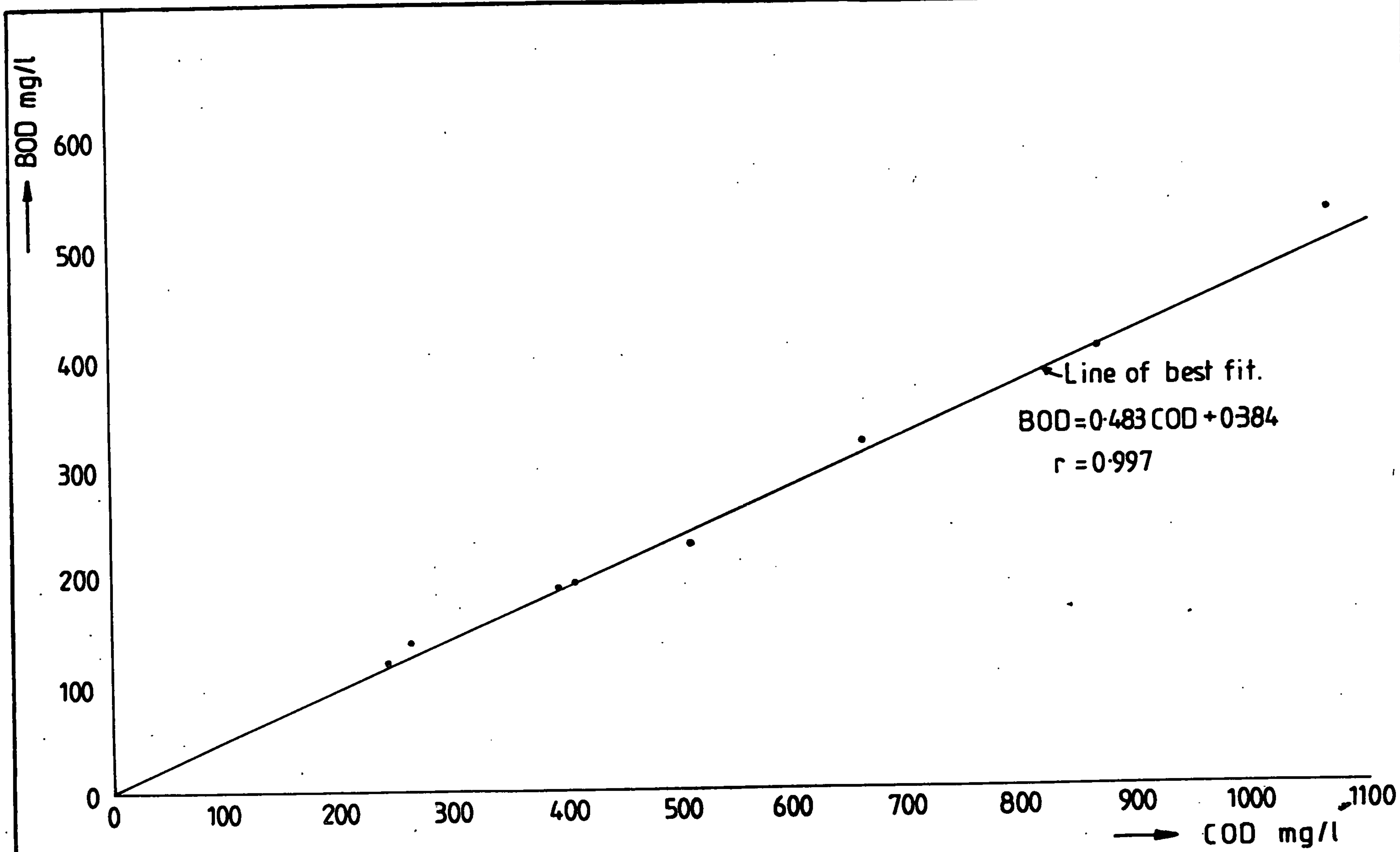

Fig. 2. Relationship between BOD and COD for Raw Waste water.

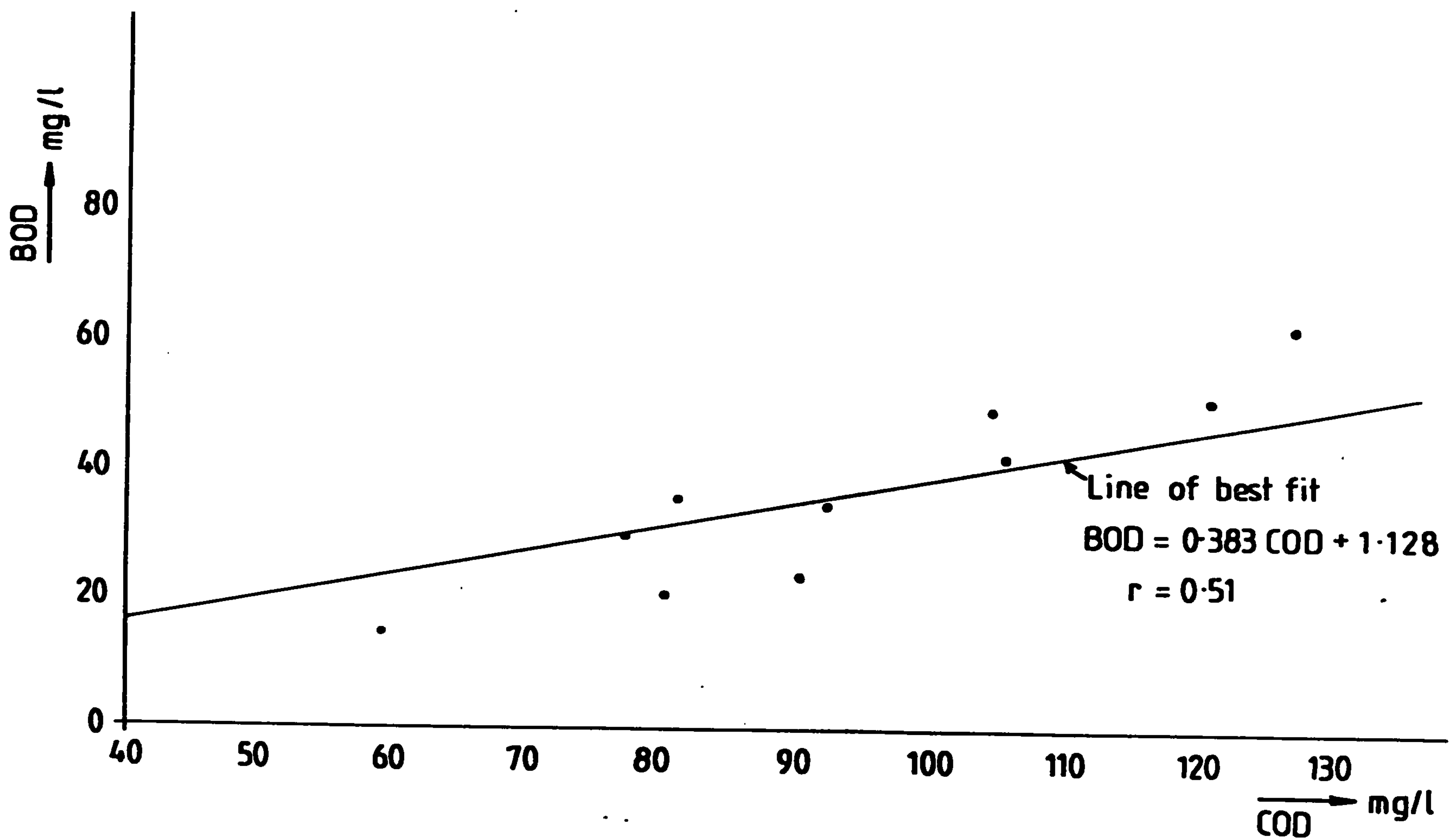

Fig.3. Relationship between BOD and COD for Pond effluent.

A well stabilized effluent will have a TI of 0.1.

Practically stabilized effluent for example from efficiently operated Conv. treatment plants the TI will be 0.1 to 0.3.

Insufficiently stabilized (normally from single waste stabilization ponds) effluent TI will be 0.3 to 1.0.

Average treatability indices obtained for Effluents from runs 2 and 3 are more or less the same (0.57 and 0.59) but there is remarkable improvement in the reduction of TI from second to the third run (i.e. from 0.32 to 0.39).

Pond Performance

Data collected enabled organic (both surface and volumetric) loadings and removal rates to be calculated. Pond performance was established on the basis of COD, BOD removals and reduction in treatability index. Pond efficiencies were calculated on the basis of unfiltered BOD and unfiltered COD for influent and filtered BOD and filtered COD for effluent. As recommended by Arceivala etal (1970) and Gloyna (1971) the hydraulic retention was maintained above 5 days, in order to work the pond as a facultative unit. Volumetric organic loadings are also included since the depths of ponds reported in the literature vary from installation to installation.

Results suggest that the performance improved with the decrease in organic loading and increase in hydraulic retention. The first run with an average surface loading of 1370 Kg BOD/ha.d at a hydraulic retention of 5.2 d produced an efficiency of 73% BOD removal. During this run the pond emitted unpleasant odours and also had floating scum on the surface. The reduction in treatability index was only 0.02, however, DO was detected at the surface between 10 a.m. and 5 p.m.

The second run with an average surface loading of 1054 Kg BOD/ha.d at a hydraulic retention of 6.5 d produced an efficiency of 83% BOD removal. During this run the pond emitted mild odour (slightly more in the early hours of the morning) and had occasional floating scum. The treatability index of effluent was 0.57 with an average reduction of 0.32.

The third run with an average areal loading of 636 Kg BOD/ha.dat a hydraulic retention of 11.3 d gave a BOD removal efficiency of 86%. Treatability index of effluent was 0.59 with a reduction of 0.39. During this run the pond was always green in colour, there was absolutely no scum formation on top, but there was mild odour, detected in the early hours of the morning and that too only when standing near the pond. Ratnayake and Sandanam (1985) reported that the per capita BOD for Colombo wastewater as 37 g, based on this assumption this pond loaded at 636 Kg/ha.d will require only 0.8m^2/capita compared to 1.0 to 3.0 m^2 per capita as reported by Arceivala (1986) for normal ponds in warm climate countries.

Oswald (1968) recommends for effective BOD removal, Anaerobic conditions at the pond bottom should be encouraged by

(i) Increasing pond depth
(ii)Increasing pond loading or both.

He reports that the methane fermentation may be regarded as an indispensable condition for nuisance free Anaerobic and facultative pond performance. But methane producing bacteria are very sensitive to DO and one of the major advantages of deep ponds is the protection of the Anaerobic zone from DO intrusion. Fluctuations in temperature and pH which may hinder (or negate) the establishment of methane bacteria, are also less likely to occur in deep ponds. It is well established that deeper ponds accumulate more heat and maintain more uniform temperature compared to shallow ponds. For effective methane fermentation a minimum temperature of 15°C to 19°C is required and the minimum temperature of 27°C recorded at the pond bottom during this study suggest that under our climatic conditions the temperature is not likely to be depressed below the minimum required for methane fermentation.

Experience from India as reported in Decade of research (1978) indicates a very deep primary pond of 4.05 m loaded at 440 Kg BOD per ha.d at a hydraulic retention of 14.5 d produced 89% BOD removal. Performance of a 5 m deep secondary pond as reported from Israel by Wachs and Berend (1968) indicates a BOD removal efficiency of more than 80%.

Many researchers have stressed that the important external factors influencing the primary facultative pond process include pond depth, areal organic loading, hydraulic retention time, temperature and solar radiation. Engineering interest mainly lies in understanding these factors particularly loading, depth and retention which influence pond performance and in optimising the performance without creating offensive conditions. Field studies are in progress to determine the diurnal variations of pH, DO, temperature, COD and suspended solids at 0 m, 1.0 m, 2.0 m and 3.0 m from the surface in order to obtain more information on the behaviour of this deep waste stabilization pond.

Conclusions

Based on the results of this study the following conclusions can be drawn :

a) The BOD of Sri Lankan domestic wastewater may be reliably obtained by multiplying the COD value by 0.48.
b) Under our climatic conditions, use of high loaded deep primary ponds may produce reasonably good quality effluent with only $0.8m^2$ capita of land including provision for bunds and roads.
c) A 3.6 m deep pond may be loaded as high as 636 Kg BOD/ha.d at a hydraulic retention of 11.3 d without developing nusiance or objectionable conditions.
d) Organic loading of this pond may be safely increased to about 1000 Kg BOD/ha.d at hydraulic retention of 6.5 d if it were to be used as a pre-treatment unit, provided it is located away from residential area.

Acknowledgement

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Table 1

Mean Experimental Results (and range)
obtained for the pond
(six sets of determinations in each run)

	Run 1	Run 2	Run 3
Raw wastewater Flow Q (m^3/d)	13.7 (13.2-14.2)	11.1 (9.9-12.1)	6.3 (6.0-6.7)
Influent (unfiltered)			
COD (mg/l)	406 (390-426)	398 (384-421)	403 (340-444)
BOD (mg/l)	197 (188-205)	187 (175-201)	199 (172-214)
Hydraulic retention time (d)	5.2 (5.0-5.4)	6.5 (5.9-7.2)	11.3 (10.6-11.9)
Effluent (filtered)			
COD (mg/l)	113 (101-130)	88 (78-94)	73 (63-89)
BOD (mg/l)	54 (43-67)	32 (28-36)	27 (24-31)

Table 2

Mean total COD and total BOD of
Raw Wastewater

COD mg/l	BOD mg/l
1066	530
866	405
659	322
509	230
410	197
396	190
265	141
246	123

Table 3

Mean Soluble COD and Soluble BOD
of Pond Effluent taken from 3 runs

COD (mg/l)	BOD (mg/l)
126	63
120	52
104	50
105	43
92	35
90	24
81	36
80	21
77	30
59	15

Table 4

Pond Loading and Performance

	Run 1	Run 2	Run 3
Hydraulic retention time (d)	5.2	6.5	11.3
Organic Areal loading			
Kg (BOD/ha.d	1370	1054	636
Kg COD/ha.d	2823	2243	1288
Organic Volumetric loading			
g BOD/m^3.d.	38	29	18
g COD/m^3.d.	78	62	36
Removal efficiency percentage			
BOD	73	83	86
COD	72	78	83
Treatability Index			
Influent	0.94	0.89	0.98
Effluent	0.92	0.57	0.59
Reduction of TI in the pond	0.02	0.32	0.39