14th WEDC Conference

Water and urban services in Asia and the Pacific

Kuala Lumpur 1988

Efficiency of oxidation ponds

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INTRODUCTION

Oxidation pond is being widely used in Malaysia in particular for the treatment of domestic wastewater in residential areas. It has been the recommended treatment method in Malaysia and is popular particularly as it is cheap, easy to construct and maintain. Eventhough its use has been quite extensive, data on its operation is limited. Available data are also rarely analysed and published.

There are numerous studies on oxidation ponds carried in other countries notably by Gloyna(1), Mara(2), Sauze(3) and Marais(4). However the results obtained have to be compared to the data obtained in Malaysia in order to determine its applicability. Work on the design and performance of oxidation pond in Malaysia have also been reported by Maheswaran et al(5) and Tan Hoo(6). Here the results of water quality, flow data and tracer experiment obtained from two oxidation ponds will be discussed.

THEORY

The aerobic biological decomposition in an oxidation pond can be described as a first order reaction such as

$$dI/dt = -k\,t \qquad (1)$$

where I is the concentration of organic matter, t is the retention time and k the rate constant. The above equation can be integrated and given in terms of y, the BOD at time t and Iu, the ultimate BOD. The resultant equation is given as

$$y = Iu\,(1 - e^{-kt}) \qquad (2)$$

The above mentioned equation is for the carboneceous decomposition only. However the nitrogenous demand can be incorporated if its rate constant is known.

The pond system studied can be considered as ideal reactors such as a plugflow (PF) reactor or as a completely mixed flow reactor (CMF). From material balance and using first order kinetics the relevent equations are as follows;

$$\text{PF} \qquad Ie / Io = e^{-kt} \qquad (3)$$

$$\text{CMF} \qquad Ie / Io = 1/(1 + kt/m)^{m} \qquad (4)$$

where Io and Ie are the organic concentration at the influent and effluent of the pond respectively. The number of stages for the CMF reactor is denoted by m.

The time refered to in the above equations is the mean retention time. This is normally obtained using the hydraulic retention time with the design volume of the pond and the volumetric flowrate of the wastewater. However this does not take into consideration the non ideality of flow in the pond which has shortcircuiting and stagnant regions.

The non ideality of flow in the ponds can be characterised by determining the residence time distribution of the pond using tracers. Defining that Edt is the fraction of tracer in the exit stream that has a retention time between t and t+dt, then it follows that (9)

$$\int_0^\infty E\,dt = 1.0 \qquad (5)$$

and the mean retention time of the pond can be given as

$$\bar{t} = \frac{\text{retention time } t \times \text{fraction of the effluent stream with a retention time between } t \text{ and } t+dt}{\text{fraction of effluent stream with retention time between } t \text{ and } t+dt}$$

or

$$t = \frac{\int_0^\infty t\,E\,dt}{\int_0^\infty E\,dt} = \int_0^\infty t\,E\,dt \qquad (6)$$

The fraction of organic matter that is converted in the pond would depend on the time it spend in it. The summation of all elements of the effluent with the different retention time will give the overall conversion of the organic matter. Using the first order reaction for organic decomposition the resultant equation is

$$Ie = Io\int_0^\infty e^{-kt}\,E\,dt \qquad (7)$$

MATERIAL AND METHODS

The experiments were carried out at two ponds sites namely at the Wardieburn Army Camp and the residential area at Seri Serdang. The pond system at Wardieburn consists of two ponds in series and the latter consists of two identical systems in parallel each with two ponds in series (four ponds in total, considered as two pond systems namely SS1 and SS2). The total pond volume at Wardieburn is 16500 m3 and that at Seri Serdang is 12000 m3 (total for two ponds in series).

The sampling was carried out using the Manning S-4040 automatic sequential sampler. A 24 hr measurement were done by taking 2 hourly composite samples (sampling at every 15 minutes interval). The parameters analysed are the biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), Oil and Grease, alkalinity, Total Kjedahl Nitrogen, Temperature, pH, nitrate and ammoniacal nitrogen. All were analysed according to standard methods(11) except the last two parameters which were done using the Hash water quality kit. The dissolved oxygen (DO) was measured in-situ at depths of about 5 and 50 cm from the surface. The time of measurement correspond to the minimum (before 10:00 am) and maximum (between 2:00 and 4:00 pm) DO value expected for the day.

The flow measurements for the Seri Serdang ponds were done using Parshall flumes. This was carried out on six different days each for a period of 24 hr. Flow data for the Wardieburn pond were obtained from City Hall (data from 1970 to 1975 and extrapolated for latter years based on population served).

To characterise the pond at Seri Serdang, a joint study using radiotracer was carried out with the help of the Atomic Energy Unit (UTN). In this case a pulse input of radioactive tracer Tritium was added to the influent of the pond. The respond was determined by sampling at the outlets of the first and second ponds. The Tritium has a half-life of 12.4 years and therefore its disintegration can be ignored in calculating the residence time. Tritium is naturally available in the environment with a base value of approximately 200 cpm counts per min-20min).

RESULTS AND DISCUSSION

Mean Hydraulic Retention Time

The designed hydraulic retention time for the Seri Serdang pond systems SS1 and SS2 are 7.7 days each and that for Wardieburn is 9 days. The present retention time for the Wardieburn pond estimated from population projection is only 5.7 days. This is due to overloading and sludge accumulation in the first pond. The present population served is 12000 compared to the designed capacity of 8000 only. The amount of sludge accumulated at the first pond was measured at 3570 m3 after 15 years of operation.

The volumetric flowrate for each of the ponds systems at Seri Serdang were found to range from 1040 m3/day to 1310 m3/day with an average of 1220 m3/day. This corresponds to a mean hydraulic retention time of 9.6 days.

The retention time of the pond can also be calculated using the tracer studies. The respond obtained from the experiments are given in Figures 1 and 2. Using equation 6 the retention time for the first pond is calculated to be 3.3 days and 5.6 days for the two ponds in series. Compared to the value obtained using flow measurements, the actual retention time is lower. This is due to the sludge accumulation and the ineffectiveness of certain sections of the pond (dead zones and short-circuiting occurs).

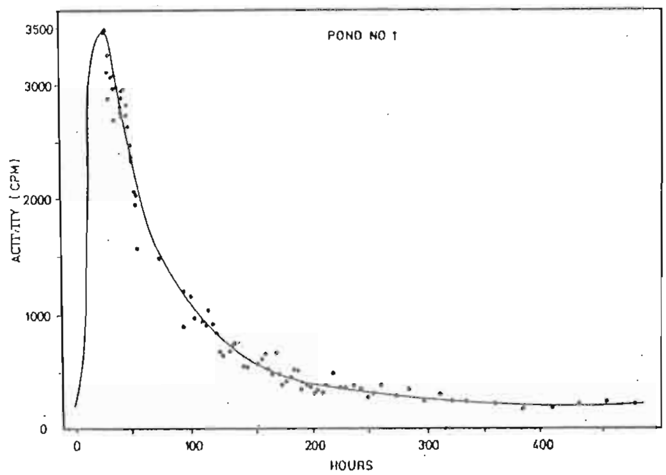

Figure 1. Response at the exit of first pond

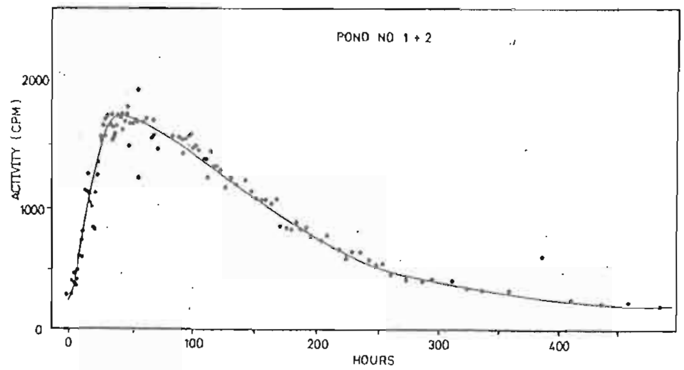

Figure 2. Response at the exit of two ponds in series

Effluent Quality

BOD The input BOD data for Seri Serdang ponds system I and II are given in Figure 3. The data is the average of 5 different sampling days and categorised into two-hourly intervals. The average influent BOD is 137 mg/1 with a maximum of 188 mg/1 and the average effluent BOD were 28 and 35 mg/1 respectively. The removal efficiency in terms of quality is between 74 to 80%. As for the Wardieburn pond, the efficiency reduces from 80% BOD removal to 70% after 15 years of operations. However it has to be noted that the pond was oversized during the initial period and overloaded at present.

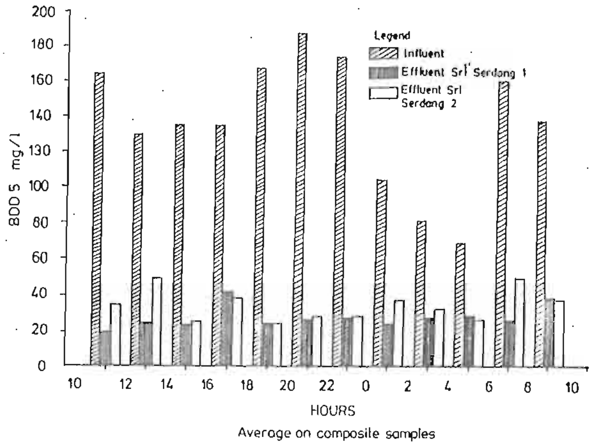

Figure 3. Daily average of 2 hourly composite samples (BOD)

The BOD removal is not totally due to bio-oxidation. Test on the influent water shows that the BOD reduces by as much as 30 to 70 % , with an average of 47% simply by letting the sample settled for 2 hours.

COD The COD data were also obtained from the same samples. The influent COD at the Seri Serdang pond ranges from 140 to 300 mg/1 with an average of 210 mg/1 (Table 1). The effluent COD averages at 114 and 120 mg/1 for the parallel pond systems. The average influent and effluent COD for Wardieburn were 202 and 112 mg/1 respectively(Table 1).

The reason for the high COD value can be due to limited oil and grease removal (Table 1) and the growth of algae. The latter was confirmed by filtering the effluent prior to COD analysis. The results on 13 samples showed the average ratio of filtered to unfiltered sample to be 0.6. Therefore the effluent after algae removal can be about 56 to 80 mg/1.

Suspended Solids The average influent and effluent suspended solids (SS) are given in Table 1. The effluent for the Seri Serdang pond 1 and 2 were 46 and 92 mg/1 respectively. The inlet and outlet for Wardieburn pond were 141 and 68 mg/1 respectively. Here again the high SS is mainly due to the presence of algae.

Table 1. Daily average of the inlet and outlet water quality (values given are means with standard deviations in parenthesis)

	Seri Serdang			Wardieburn	
	in	out1	out2	in	out
Temp. (C)	29(1)	30(1)	30(2)	29.5	33.6
pH	7.3(0.1)	7.4(0.1)	7.7(0.1)	7.0(0.1)	7.4(0.1)
Alkal.(mg/1 CaCO3)	198(26)	162(5)	166(5)	-	114(5)
COD (mg/1)	210(53)	114(10)	120(19)	202(83)	112(18)
SS (mg/1)	199(126)	46(20)	92(45)	141(58)	68(15)
N-NTK (mg/1)	23(5)	22(1)	-	-	21(2)
N-NH4+ (mg/1)	0.9(0.2)	2.0(0.1)	2.1(0.1)	1.7(0.2)	2.0(0.1)
N-NO3- (mg/1)	1.6(0.2)	1.0(0.2)	0.6(0.2)	1.8(0.5)	0.9(0.2
O/Grease (mg/1)	154(64)	93(21)	-	-	-

pH, Alkalinity and Nitrogen Content The pH of the effluent of the pond are higher than the influent (Table 1). The increase in pH represents the uptake of carbon dioxide in the water by the process of photosynthesis. On the other hand the alkalinity of the wastewater decreases after treatment indicating the use of inorganic carbon by the algae is greater than the carbon dioxide input by bio-oxidation. Thus the photosynthetic activity of the pond is high and the biological process is low.

The degree of nitrification in the pond was low. Only the initial step of nitrification, the ammonification step occurs (Norg-->NH4+). The Total Kjeldahl Nitrogen of the wastewater remained constant.

Modelling

In modelling the oxidation pond two methods for calculating the rate constant were used. The first is by assuming the ponds as ideal flow reactors such as the plugflow and the completely mixed flow reactors. The second is by the use of tracers to determine the actual residence time distribution of various fraction of water flowing through the ponds.

The two flow models PF and CMF were chosen as they represent the simplest models and also gives the two extreme volume efficiencies that can be expected. Uhlmann (7) , Mara (2) and Thirumurthi (8) have suggested the used of CMF models as it represents better, the dead zones and the short circuiting that is expected and also tends to overdesign the pond size.

For CMF model the rate constant can be calculated from equation (4) given that m=2. In the case of PF model the rate constant can be calculated using equation (3). The results are summarised in the Table 2. The k value calculated for the Wardieburn pond is base on the 1985 data and taking into account of volume loss due to sludge accumulation.

Table 2 k values (day-1)

Location		Pond 1+2	Pond 1
Wardieburn	PF	0.237	0.408
	CMF	0.345	0.675
Seri Serdang	PF	0.134	
	CMF	0.180	
	RTD	0.385	0.695
(2h settl)	RTD	0.210	0.325

The k value for the Seri Serdang ponds are also given in Table 2. These values were calculated based on the 24hr flow measurements. The k = 0.18 day-1 obtained for CMF was actually close to 0.17 day-1 value recommended by Marais (4). It is interesting to note that with the residence time distribution studies, the k value calculated by trial and error using equation (7) and Figures 1 and 2, is much higher. This is because the actual effective volume of the pond is reduced and there is settling particularly in the first pond. The effect of settling can be incorporated by using the BOD after 2 hr settling as the influent. In which case the k value of 0.21 day-1 that was obtained is more consistent.

The results from Table 2 also show that the k values calculated using CMF model approximates the RTD studies data better than the PF model. This shows that the CMF model is a better approximation to the actual situation. This is also evident from Figure 1 and 2 which resembles the shape expected from a single CMF and two CMF in series models respectively.

CONCLUSION

The effluent quality from oxidation ponds can comply with the requirements of Malaysian Effluent Discharge Standard B with the exception of COD and SS. This is mainly due to the presence of algae. The ponds studied regularly fail to meets the requirements of Standard A. The use of the CMF model to describe the ponds is a satisfactory assumption, in particular to the residence time distribution patterns obtained. A k value of 0.17-0.21 day-1 seems to be reasonable for the local condition. The former is appropriate to be used in conjunction with the CMF equations and the latter if more detail flow characteristics of the pond is known. The tracer study also shows that the pond design does not fully ultilise the total available volume of the pond and further work in this area should be done.

ACKNOWLEDGEMENT

The authors thanks Unit Tenaga Atom for all their help and cooperation in carrying out the radiotracer study, City Hall for the use of their data and the French Embassy and the Ministry of Housing and Local Government for their support and help in the study.

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