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Application of Ponding Systems in the Treatment of Palm Oil Mill and Rubber Mill Effluents

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RINGKASAN

Kolam telah dicadangkan sebagai satu cara yang murah untuk memproseskan efluen-efluen dari kilang kelapa sawit dan kilang getah. Pertimbangan-pertimbangan tioretikal telah diulas dan dibincangkan bersangkutan dengan rekabentuk kolam. Rekabentuk untuk model-model empirikal dan rasional telahpun dibentangkan. Model-model tersebut dianggap sebagai pemilihan yang paling tepat untuk rekabentuk kolam. Kegunaan-kegunaan sistem-sistem kolam untuk efluen-efluen kelapa sawit, getah dan betongan tempatan di Malaysia telah dibincangkan. Angkali kinetik tingkat pertama untuk efluen-efluen kilang getah telah diperolehi berdasarkan pada data-data sistem kolam yang telah wujud. Angkatap-angkatap ini bernilai dari 0.065 hingga 0.27 hari^{-1}. *Angkali kinetik untuk efluen kilang kelapa sawit bagi sistem campuran sebati dan sistem aliran "plug" juga dibentangkan. Angkali untuk kolam yang menunjukkan aliran "plug" telah didapati bernilai 0.068 hari*$^{-1}$. *Kekurangan data telah menghalang usaha terbitan angkatap kinetik bagi kolam-kolam oksidasyen betongan tempatan. Data kos untuk perbandingan diantara sistem kolam dan sistem-sistem lain telah diperolehi dari sistem-sistem memproseskan efluen secara anaerobik di kilang kelapa sawit yang telah wujud.*

SUMMARY

Ponding is proposed as a viable low-cost treatment method for palm oil and rubber mill effluents. Theoretical considerations were reviewed and discussed in relation to the design of ponds. Both empirical and rational design models were presented. Adoption of such models were deemed closest to a way of designing ponds. Applications of ponding systems for palm oil mill effluent, rubber effluent and domestic sewage in Malaysia were discussed. Some first order kinetic coefficients were calculated for rubber mill effluents based on data for existing ponding systems. These constants ranged from 0.065 to 0.27 day^{-1}. *Kinetic coefficients for palm oil mill effluent for both completely mixed and plug flow systems were also presented. The coefficient for a pond exhibiting plug flow was found to be 0.068 day*$^{-1}$. *Insufficient data prevented the derivation of kinetic constants for domestic sewage oxidation ponds. Costs data were derived from existing palm oil mill effluent anaerobic treatment systems for comparison between ponding and other systems.*

INTRODUCTION

Ponding is a general term which includes waste stabilization lagoons (ponds) and oxidation ponds. The term oxidation pond has also been loosely used and can mean aerobic, facultative, maturation or sometimes it may even be used for anaerobic ponds. Ponding essentially employs a biological method of treatment for wastewaters. It is also used for settling of sludge or suspended solids (sedimentation ponds).

Ponding can be used where land space is available. It can achieve a reasonable degree of treatment, is low in construction and operating costs and is easily maintained as the technology required is relatively unsophisticated. Ponds have been used extensively in several other countries for the treatment of industrial wastewaters amenable to biological treatment. Ponding has been used in oil refineries, slaughterhouses, dairies, piggeries, poultry-processing plants and even chemical works. Wherever necessary, nutrients are added to help raise the BOD: N:P ratio to 100:5:1 in order for ponds to function efficiently in industrial installations.

Ponding has been applied to a considerable extent in Malaysia. Palm oil mill effluent, rubber factory effluent and domestic sewage effluent have all been treated in this manner (Wong and Springer 1980; John and Ong 1979; Asairinachan 1979).

This paper deals with the theoretical considerations for ponding systems, design criteria, local applications and cost estimates.

THEORETICAL CONSIDERATIONS

Biological treatment processes can basically be divided into:

(a) aerobic

(b) facultative

(c) anaerobic

Each one of the above processes involves biological cells which require a chemical substrate and some optimal physical conditions for their growth and survival before they ultimately decay.

Scientists have attempted to rationalise the growth of bacterial cells (including those involved in the treatment of wastewaters), into simplified growth models with accompanying involvement of growth kinetics (Monod 1949; McCarty 1966; Pearson 1968; Thirumurthi 1974; Marais 1970, 1974). These will be discussed in this section.

Design Equations

Pond designs can be derived from equations which are in turn arrived at from either:

(a) empirical data from actual field experience

or (b) a rational design model employing an understanding of biological kinetics.

BOD is usually used as the pollution parameter to describe the performance and design of a pond.

Areal or surface BOD loading λ_s is the weight of BOD applied per unit area of pond per day and is given as:

$$\lambda_s = \frac{10\, L_i\, Q}{A} \qquad \text{.......................... (1)}$$

where A = Area of pond in hectares
Q = Flow rate of wastewater in m^3/day
and L_i = Influent BOD in kg/m^3

Volumetric loading rates are sometimes used particularly with anaerobic ponds. If λ_v is the weight of BOD applied per unit volume per day then

$$\lambda_v = \frac{L_i Q}{AD} \qquad \text{.............................. (2)}$$

where D = pond depth

$$\text{and } \frac{AD}{Q} = \text{retention time} = t$$

$$\text{Then } \lambda_v = \frac{L_i}{t}$$

In facultative ponds, λ_v is usually in the range of 15–30 g/m^3 day whilst anaerobic ponds develop odour at $\lambda_v > 100$ g/m^3-day (Mara 1976).

Empirical models for industrial wastewater treatment using ponds are still seriously lacking. Most empirical models have been based upon domestic sewage and are only for facultative ponds. Industrial waste ponds represent the most complex of the ponding systems often involving aerobic, anaerobic and settling processes. The discussion of empirical models below is only limited to domestic sewage.

McGarry and Pescod (1970) found that areal BOD_5 removal, L_r, may be estimated through knowledge of areal BOD_5 loading, L_o by

$$L_r = 9.23 + 0.725\, L_o \qquad \text{........... (3)}$$

Larsen (1974) proposed an empirical design model for pond surface area as follows:

$$\text{MOT} = (2.468^{\text{RED}} + 2.468^{\text{TTC}} + 23.9/\text{TEMPR} + 150.0/\text{DRY}) \, . \, 10^6 \qquad \text{........ (4)}$$

where the dimensionless products:

$$\text{MOT} = \frac{\text{surface area (solar radiation)}^{1/3}}{\text{influent flow rate (influent BOD}_5)^{1/3}}$$

$$\text{RED} = \frac{\text{influent BOD}_5 - \text{effluent BOD}_5}{\text{influent BOD}_5}$$

$$\text{TCC} = \frac{\text{wind speed (influent BOD}_5)^{1/3}}{(\text{solar radiation})^{1/3}}$$

$$\text{TEMPR} = \frac{\text{lagoon liquid temperature}}{\text{air temperature}}$$

and,

DRY = relative humidity

Larsen thus related solar radiation, wind speed and temperature to the pond design.

Gloyna (1976) proposed the following equation for a facultative pond design:-

$$V = 3.5 \times 10^{-5}\ QL_a\ (\alpha^{(35-T)}\ f\,f' \quad \ldots (5)$$

where,

V = pond volume, m^3

Q = influent flow rate, l/d

L_a = ultimate influent BOD$_u$ or COD, mg/l

α = temperature coefficient

T = pond temperature, °C

f' = algal toxicity factor, and

f = sulphide oxygen demand

All these empirical equations for waste stabilization pond design appear to be peculiar and particular to the cases that they are derived from and the design of ponds in Malaysia need not necessarily follow these equations.

Rational design equations may be of some assistance to pond designers. Marais (1970) proposed first-order kinetic equations for describing *completely mixed ponds* as follows:

$$\frac{L_e}{L_i} = \frac{1}{1 + k_1 t} \quad \ldots\ldots\ldots\ldots (6)$$

where

L_e = BOD in effluent (mg/l)

L_i = BOD in influent (mg/l)

k_1 = first order kinetic constant

t = retention time

This model was adopted by Wong and Springer (1980) in their evaluation of anaerobic ponding systems for palm oil mill effluent (POME). The model could justify the design of functioning and completely mixed ponding systems for POME. This equation has also been applied on aerated lagoons.

To take into consideration temperature Marais suggested that

$$k_T = k_{T_o}\ \alpha^{(T-20)} \quad \ldots\ldots\ldots\ldots (7)$$

where,

k_T = kinetic constant at temperature T

k_{T_o} = kinetic constant at temperature T_o

and

α = temperature coefficient

α was reported to be 1.047 by Bishop and Grenney (1976) for domestic sewage.

In a *plug flow* ponding system (more like a long ditch) Mara (1976) reported the following design equation:

$$L_e = L_i\ e^{-k_1 t} \quad \ldots\ldots\ldots\ldots (8)$$

Limitations of first-order kinetics have been considered by studies on composite and retarded exponential models (Gameson *et al.* 1958) and second order kinetics (Young and Clarke 1965; Tucek and Chudoba 1968). Wehner and Wilhelm's (1958) model for first-order bioxidation reaction in *dispersed flow* is complex for simple pond designs, but nevertheless can be used. The justification for using a more complex model was supported by Thirumurthi (1974) who refuted the use of a completely mixed flow model in the rational design of stabilization ponds. He found that facultative ponds exhibit nonideal flow patterns and recommended the use of Wehner-Wilhelm's chemical reactor equation for pond design:

$$\frac{L_e}{L_i} = \frac{4ae^{1/2\,d}}{(1+a)^2\,e^{a/2d} - (1-a)^2\,e^{-a/2d}} \quad \ldots (9)$$

where,

L_e = effluent BOD$_5$, mg/l

L_i = influent BOD$_5$, mg/l

k = 1st order BOD$_5$ removal coefficient, day^{-1}

a = $1 + ktd$

t = mean detention time

d = dimensionless dispersion number

and d = D/uL

where,

D = axial-dispersion coefficient, m^2/h

u = fluid velocity, m/h

L = characteristic length, m

Thirumurthi's definition of k is

$$k = K_8 C_1 C_2 / C_3$$

where,

K_s = standard BOD_5 removal coefficient
C_1 = correction factor for temperature
C_2 = correction factor for organic load
and, C_3 = correction factor for toxic chemicals

More recently Finney and Middlebrooks (1980) disputed the applicability of both empirical and rational design models. They were not satisfied because the empirical and rational models could not predict their published pond performance data. They believed that the hydraulic retention time used in many of the design equations had very little research done on them.

DESIGN CRITERIA AND PERFORMANCE OF PONDS

As both the empirical and rational equations can be subjected to questioning for particular types of pond, with a particular climate and a particular effluent, it would be more reasonable to base designs on a range of performance. Metcalf and Eddy (1979) provided information for design of all the different types of ponds with a range of design criteria.

A number of different approaches have been used to design *aerobic ponds* (Gloyna 1971; Marais and Capri 1970; McKinney 1971). Generally first-order kinetics can be applied and the kinetic constants can be determined through actual operating data – something hard to come by for industrial wastewaters.

Depending on the type of flow regime the design of both facultative and anaerobic ponds may also employ first order kinetic equations. The design can be more accurate if the dispersion factor, d, is known in the Wehner-Wilhelm equation. The value of k can be calculated from Figure 1 (after Thirumurthi 1969). For facultative ponds with aerators, the aerators should have a capacity adequate to satisfy from 175 to 225% of the incoming BOD^5. Such ponds are in existence in Malaysia but are not considered here.

Accumulation of sludge can be a serious problem for wastewaters with high solids content for this would reduce the performance of ponds. Very often operators think that, because ponding requires minimal maintenance, they can therefore be left on their own. This has actually happened for a lot of anaerobic and facultative ponds treating palm oil mill effluent. They are either sour, overloaded or all clogged up because of poor mixing. Ponds do need maintenance and occasional desludging.

SOME PONDING SYSTEMS IN MALAYSIA

Ponding has been used considerably in Malaysia in the treatment of the two main agro-industrial effluents: rubber and palm oil mill effluent.

There are several types of rubber effluents: block rubber, sheet rubber, crepe rubber and latex concentrate effluent. Ponding systems have been investigated by several workers (Muthurajah *et al.* 1973; John *et al.* 1974; Ponniah *et al.* 1975; Ponniah *et al.* 1976; Ahmad *et al.* 1979; John and Ong 1979; John 1979).

Ponding systems in palm oil mill effluent have also been reported (Seow 1977; Wong and Springer 1980). Anaerobic ponds are usually the first stage in the treatment of POME.

In domestic sewage wastewater treatment, there is ponding, activated sludge, extended aeration and diffused air in use in Malaysia (Asairinachan 1979). The efficiency of BOD removal in the oxidation ponds ranged between 74 to 81%. As influent BOD was around 190 mg/l an effluent. BOD of less than 50 mg/l could be achieved. For a 2-stage oxidation pond system a 450 kg/ha/day BOD loading rate with an expected BOD discharge of less than 50 mg/l can be realised.

CALCULATIONS OF DESIGN CRITERIA FOR RUBBER AND PALM OIL MILL EFFLUENT PONDING SYSTEMS

The models presented in section 2 provide a basis for the choices of rational models used in the calculations of design criteria for rubber and palm oil mill effluent ponding systems.

The empirical models outlined are models derived for specific wastewaters treated under operating conditions which are applicable only to those particular climate and pond configurations. As these models were arrived at in countries which are climatically very different from Malaysia and as the wastewater considered is mainly domestic sewage, the empirical models presented are not acceptable.

Rational design models were thus selected based not only on the process of elimination but also upon the immediate need for guidelines to design ponds of the right configuration and treatment capability to process rubber and palm oil mill effluents.

As discussed in the Section on "Design Criteria and Performance of Ponds" the flow regime is important for selecting the type of rational model used for designing ponds. Two limiting cases are available, i.e. completely mixed flow and plug flow. Most ponds operate in a flow regime somewhere in between, depending upon the pond configuration, and, operating and maintenance procedures.

The model which accounts for the flow regime is the Wehner-Wilhelm model. As the dispersion factor, d, varies from 0.1 to 2.0 for waste stabilization ponds depending upon the configuration, certain assumptions and choices have to be made. Based upon the experience of Metcalf and Eddy (1979) on ponds of different configuration, d was taken to be 0.25 for the block rubber, sheet rubber and crepe rubber effluent as the ponds used in each respective case were actually two ponds in series. The latex concentrate effluent had four ponds in series and thus a value of $d = 0.1$ was used. This closely approximates plug flow. Figure 1 was used to derive the kinetic coefficients for these rubber effluents.

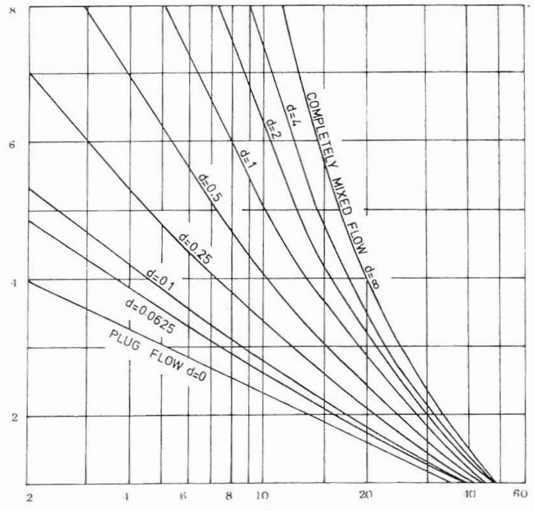

Figure 1 : Values of kt in the Wehner and Wilhelm Equation versus percent remaining for various dispersion factors.

The data on palm oil mill effluent ponding systems fitted the two limiting systems: a completely mixed flow case (Wong and Springer, 1980) and a completely plug flow case. A plug flow was assumed here because the pond used was actually a 1609.8 m long ditch with a width of about 3 to 4.6 metres and a depth of 1.3 to 2 metres.

Thus equation (6) was used for deriving the kinetic coefficients by Wong and Springer (1980) and equation (8) was used to derive the coefficient of the plug flow ponding system for POME considered here.

a. *First Order Kinetic Coefficients and Performance of Ponds Considered*

Using data on rubber effluent ponding systems, the values of the first order kinetic coefficients derived on the basis discussed above for block rubber, sheet rubber, crepe rubber and latex concentrate were found to be 0.27, 0.23, 0.16 and 0.065 day^{-1} respectively. These values are, therefore, very much a function of the pond's shape or configuration. The designer must thus be cognizant of the type of pond he is designing before he uses these values.

The first order kinetic coefficient for the completely plug flow model calculated from data of the long ditch ponding system in the treatment of POME was found to be 0.068 day^{-1}. This differed quite significantly from the value of 0.36 day^{-1} in the case of the completely mixed flow ponding system. It, however, compares very closely with the almost plug flow configuration for the latex concentrate pond.

A summary of the wastewater characteristics, performance of ponding and the calculated values of the first order kinetic coefficients and retention times are shown in Table 1.

In all these calculations BOD was used as the basis with the exception of the plug flow model for POME where COD was used. Figure 2 plots the expected value of the effluent to influent BOD (or COD) ratio at different treatment retention times for the various ponds discussed. The curves were plotted by applying the first-order kinetic coefficients derived on the various rational models using Figure 1 and equations (6) and (8).

b. *Costs*

The cost of operating ponds depends a great deal on the price of land at a specific time· If land has to be purchased to construct ponds for waste treatment the capital costs can be high. Land prices vary from M $10,000/ha in the rural areas to $1 million/ha in urban Kuala Lumpur (1979 figures).

As ponding construction costs are similar for all treatment systems, reliable data from

TABLE 1

Summary of Wastewater Characteristics, Ponding Performance and First-order kinetic coefficients for Rubber, Palm Oil Mill and Domestic Sewerage Effluents

Parameter	BOD (mg/l)		COD (mg/l)		Total Solids (mg/l)		Suspended Solids (mg/l)		Total nitrogen (mg/l)		Amm. nitrogen (mg/l)		First order Kinetic Coefficient (k)[a] (day^{-1})	Retention Time (days)
Wastewater	Raw Effluent	% removal	Raw Effluent	% removal	Raw Effluent	% removal	Raw Effluent	% removal	Raw Effluent	% removal	Raw Effluent	% removal		
Block Rubber[b]	1769	96.7	2899	92.1	1961	63.2	322	61.2	141	61	68	38.2	0.27	22
Sheet Rubber[b]	1322	95.5	2477	85.8	1976	69.6			143	58.0	73	–	0.23	22
Crepe Rubber[b]	305	89.5	846	73.3	546	18.5	7		75	30.7	6.4	–	0.16	20
Latex Concentrate[c]	3524	96.0	4849	89.0	–	–	818	56.1	602	66.4	466	71.2	0.065	64
Palm Oil Mill[d]	25000	94.0											0.36	50
POME[e]	–	–	12549	86.7	13046	64.7	5508	91.3	252	61.9	12.3	55.1	0.068	31
Domestic Effluent[f]	176	77.0	–	–	–	–	176	50.8	–	–	–	–	–	–

a. The first-order kinetic coefficient (k) was calculated from Figure 1. Values of the dispersion factor (d) range from 0.1 to 2.0 for waste stabilization ponds.

b. These were ponds in series. Value of d = 0.25

c. There were 4 ponds in series and this was assumed to be close to plug flow. Value of d was taken to be 0.1.

d. Taken from Wong and Springer (1980). As POME volume is higher and ponds larger, completely mixed flow was adopted for selected well maintained and operated ponds.

e. Data in this study was taken from a long ditch (5720 feet long) which assumes a plug-flow configuration. The first-order kinetic coefficient is based on the COD and may be slightly on the low side if converted to BOD.

f. Insufficient data from Asairinachan (1979).

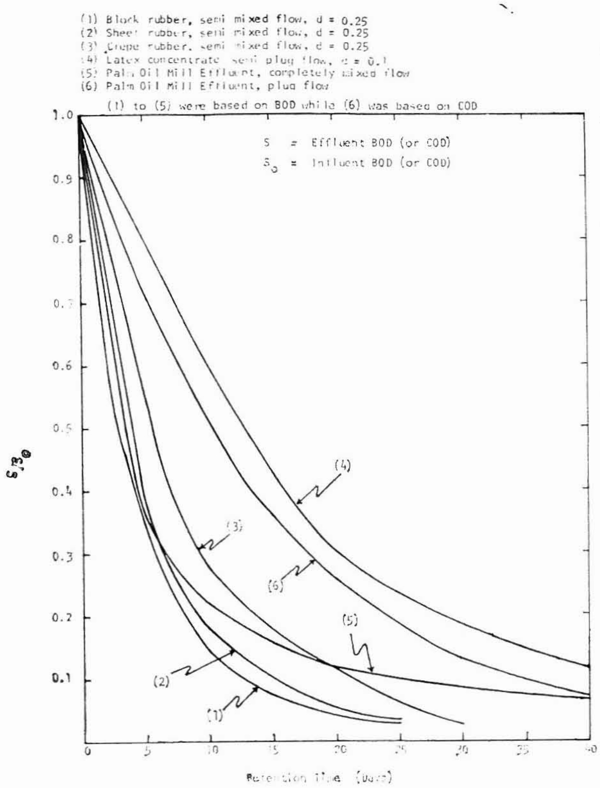

Figure 2: Performance of ponds for rubber and palm oil mill effluents.

some treatment systems for domestic wastewaters were used to analyze the financial viability of ponding systems. Table 2 shows the contrasting differences between three different treatment systems for domestic wastewaters for a population of 20,000 in terms of capital costs and land used (after Asairinachan 1979).

Although the land area required in oxidation ponds is much higher, the operating and maintenance costs are definitely lower at around M$5000 per year. Since the price of land is the constraint, Figure 3 reveals that if land is priced above M$700,000/ha (1979 figures) then a conventional activated sludge process will be cheaper than a two stage oxidation pond in terms of initial capital investment. However, we will still have to account for annual operating and maintenance costs which are definitely higher for the conventional activated sludge process. It appears that installing aerated lagoons is generally cheaper than installing oxidation ponds. With high energy prices and substantial wear and tear of mechanical parts, operating and maintenance costs in the activated sludge process can be very prohibitive. Aerated lagoons also require mechanical aeration, hence higher operating and maintenance costs. At the time of writing, local data for operating and maintenance expenditures in the conventional activated sludge and aerated lagoons for domestic wastewater treatment were not available.

TABLE 2

Construction Capital Costs and Land Requirement of Treatment Systems Sized for 20,000 people (in 1979 figures)

Treatment System	Construction Capital Cost (M$ per person)	Land Area Required (ha/10,000 persons)
Conventional Activated Sludge Plant	275.00	0.76
Two-stage Oxidation Ponds	27.50	4.25
Aerated Lagoons	30.00	1.45

Nevertheless, some indications for running costs in the anaerobic treatment of palm oil mill effluent are shown in Figure 4. The Figure shows the comparative annual costs of three systems currently used by palm oil mills in Malaysia: anaerobic ponds, unstirred open anaerobic tanks, and continuous mixed flow closed anaerobic tanks (with stirrers). These costs are for a design meant to produce an effluent BOD_3 of about 2000 ppm. The running costs (in 1979 Malaysian ringgit) include capital costs amortized at a rate of 10% over 10 years, operating costs (mainly electrical energy and manpower) and some maintenance costs. Electrical energy constitutes the bulk of the running costs.

From the examination of these costs it appears that ponding can be indeed low-cost for the industrial plant if space is available.

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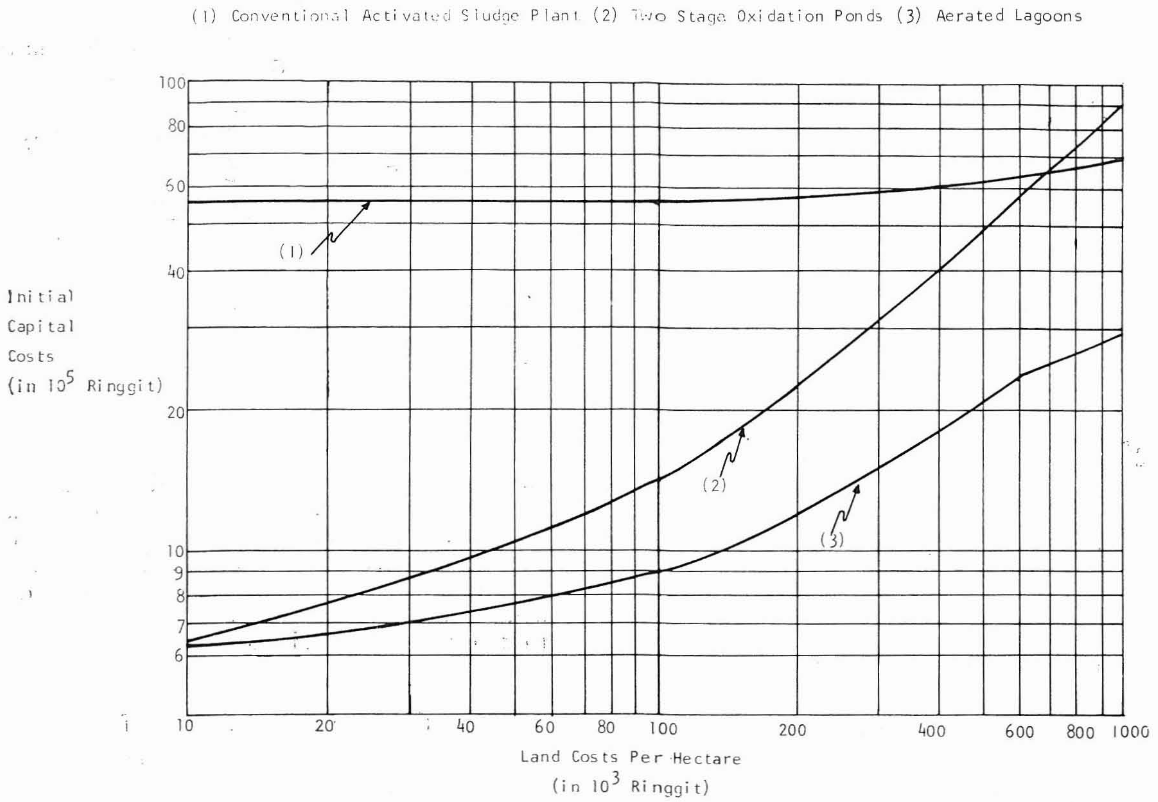

Figure 3: Initial capital costs for treatment system as a function of land price (1979 Figures)

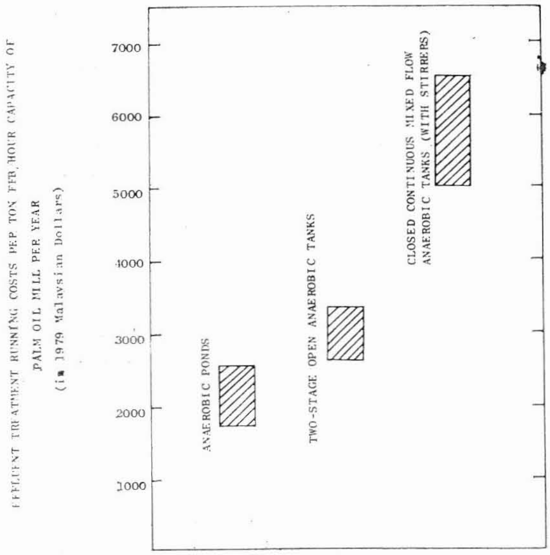

Figure 4: Running cost estimates for anaerobic treatment systems in Malaysia.

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