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# THE DESIGN OF WASTE STABILISATION PONDS

## INTRODUCTION

Waste Stabilization ponds (WSP) have been used for over 20 years, particularly in hot climates, as an effective, low-cost and easily maintained alternative to conventional systems for the treatment of domestic sewage, agricultural wastewaters and mixtures of sewage and industrial effluents. In addition, ponds have been used to treat night-soil collections, the contents of conservancy tanks, the effluents from septic tanks and aqua privies, and as a tertiary treatment at conventional works to enhance pathogen removal.

The natural processes taking place within a WSP system are controlled essentially by temperature, light intensity and detention time. WSPs are very effective therefore in the tropics where ambient temperatures are high, solar radiation is at a global maximum and the large areas of land required are often freely available. Where waterborne sewage disposal is economically and hydraulically feasible the WSP should be the preferred method of waste-watertreatment in Africa.

Despite the world wide use of ponds and the extensive literature on their design and performance, misconceptions still persist regarding their utility. Their potential for disease transmission control - especially important in most developing countries - is often not fully exploited, and difficulty in choosing suitable design criteria inevitably occurs when ponds are being planned for the first time in a distinct climatic region.

## POND SYSTEMS

A WSP system should contain at least a relatively large facultative pond for the removal of BOD, followed in series by two smaller maturation ponds for the destruction of pathogens. In the case of high strength agricultural wastewaters (for example, coffee processing and sugar refining wastes) anaerobic pretreatment units should be provided to reduce the BOD to a level (500 mg/l) that the succeeding facultative pond can cope with. To facilitate maintenance and flexibility of operation, the total area required for a pond system can be provided by parallel replicates.

### Anaerobic Ponds

An anaerobic pond functions as an open, unmixed, unheated, single-stage anaerobic digester, and to conserve heat and maintain anaerobic conditions such ponds are constructed with depths from 2 to 4M. Like septic tanks, anaerobic ponds require desludging periodically, and should be used for domestic sewage only at the larger installations when the resulting saving in land will be appreciable and where thorough maintenance can be assured.

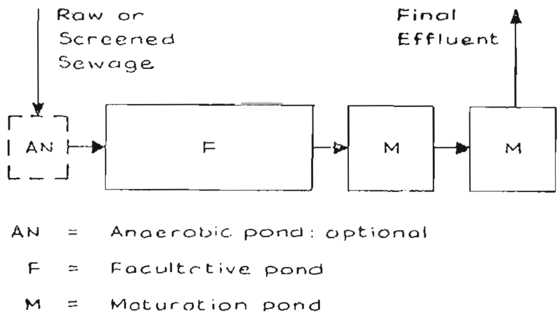


FIG. 1 WASTE STABILISATION POND SYSTEM

### Facultative Ponds

A facultative pond is usually the primary unit in a system treating wastewater of moderate strength. The depth should be in the range 1.0 to 1.6M, and the upper region is maintained in an aerobic condition by the photosynthetic production of oxygen from naturally occurring algae. Anaerobic conditions prevail towards the bottom of the pond due to the fermentation of settled sludge. The conversion of organic carbon to methane in the benthal deposits contributes significantly to the removal of BOD in a facultative pond.

A pond depth of at least 1 M. is necessary to prevent the mergence of vegetation from the pond bottom, and the depths in excess of 1.6M would lead to predominantly anaerobic conditions in the pond contents. Since a pond approximates to a completely mixed reactor, and as part of the influent organic matter is converted to algae, it is neither possible nor desirable to reduce the effluent $BOD_5$ to values less than about 60 mg/l. Indeed, the design objective should be to obtain a relatively high degree of BOD removal, while maintaining a stable balance between the aerobic and anaerobic zones during all seasons of the year.

## Maturation Ponds

In most developing countries waterborne and faecally-transmitted diseases are prevalent, and cause high morbidity and mortality rates, particularly amongst children. The principal function of maturation ponds is to extend the detention time of the pond system, and take advantage of series reactor kinetics, in order to destroy faecal pathogens. The presence of two or more maturation ponds will also reduce the BOD, and suspended solids content, to the values normally obtained from conventional works.

The sanitarily superior effluent obtained by the proper use of maturation ponds is vitally important in semi-arid regions, where many receiving streams are seasonal, such that the dry weather flow may be predominantly or entirely composed of wastewater (treated or otherwise). These same streams are frequently used for laundering clothes, growing vegetables water cattle, and may even be the only source of domestic water.

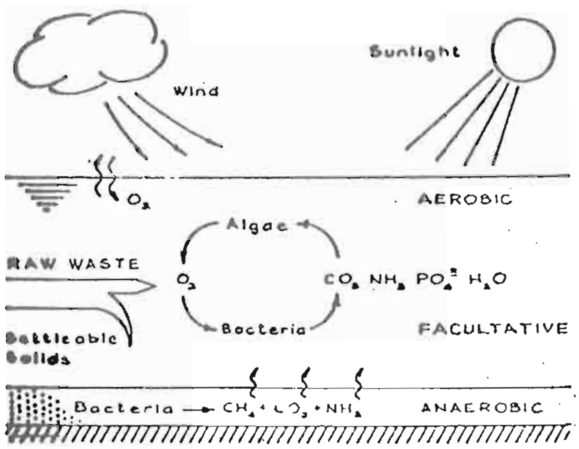


FIG. 2 FACULTATIVE POND MECHANISMS

## Standards

In a developed country where waterborne diseases have been virtually eradicated, the main aim of sewage treatment is to prevent environmental nuisance, and treatment systems are designed to minimize space utilisation and accelerate the overall purification process. Pathogens are removed only partially and incidentally.

Consequently, even where ponds are chosen for cost and maintenance advantages, the effluent standard to be achieved is often expressed solely in terms of the BOD and suspended solids removals that commonly occur in conventional works; the British Royal Commission "20/30" standard is frequently quoted in Commonwealth countries. However, this standard applies only to an effluent which can be diluted with 8 volumes of "clean" ($BOD_5$ = 2mg/l) river water. As pointed out above, tropical rivers often provide zero dilution in the dry season; in the rainy season the superabundant flow may be carrying an enormous load of silt and organic matter, rendering conventional river standards meaningless.

## Waste Stabilization Pond in Kenya

The experience of Kenya in the field of sanitation is a common one in developing countries. In the colonial period sewage systems and conventional treatment works were installed in the major urban centres and at government institutions such as hospitals, prisons and military establishments. Since independence in 1963 the ageing of plant, the lack of trained staff and the foreign exchange cost of obtaining spare parts has made it increasingly difficult to maintain such facilities.

In 1972 the Kenya Government carried out a survey of its water supply and sanitation services (Ref. 1) with a view to providing the whole population with a safe piped water supply by the year 2000, together with the concomitant sewerage facilities. The survey revealed that waterborne sewage collection was available to about 43 percent of the urban population. However, since 90 percent of the people lived in dispersed rural settlements, only 2 percent of the population outside the capital Nairobi enjoyed waterborne sanitation, 40 percent were using pit latrines, while over 50 percent of the population had no sanitation whatsoever. Furthermore, outside of Nairobi all facilities using mechanical and electrical equipment were not working properly, or had been abandoned.

Fortunately, the first WSP in Kenya was built in 1959 to replace an overloaded activated sludge plant serving Embakasi Airport, Nairobi (Ref. 2). The success of thisexperiment indicated the way forward.

## National Survey

From 1972 to 1974, the author (Ref. 3) carried out a comprehensive survey into the design, construction and performance of the existing and proposed WSP's in Kenya. In the 15 years since the Embakasi ponds were commissioned, over 35 ponds had been built to serve municipalities and government institutions in the several climatic zones of Kenya. Also, crude holding lagoons were used for treating process wastewater from a variety of agricultural industries.

From this experience it should have been possible to formulate, with confidence, empirical design criteria for future ponds in Kenya. However, the only location where measurements of effluent quality had been taken with any regularity were the ponds under the control of Nairobi City Council.

Unfortunately, no regular measurements had been taken of volumetric flow rates and influent quality, so that actual pond loadings and removal efficiencies, in terms of BOD, suspended solids and faecal bacteria, were largely unknown.

Process design of ponds had been pre-occupied solely with BOD removal based upon empirical surface loading rates, chosen arbitrarily from published performance figures from India, the Americas and Southern Africa. Design loading rates for facultative ponds ranged from 100 to 500 kg. $BOD_5$/ha d. This range is equivalent to a population served per hectare of about 2500 to 12500, representing detention times of approximately 40 to 8 days respectively.

The higher loading rates, which had led to anaerobism and failure in facultative ponds, indicates the danger of applying unthinkingly, empirical loading rates in the design of pond systems. A loading rate suitable for a facultative pond had been used to calculate the total area of a pond system (facultative plus maturation ponds), leading to the immediate overloading of the primary pond.

Since no mechanical or electrical equipment is required in pond systems, and if appurtenances are kept as simple as possible, the only regular maintenance required is that the grass is cut to prevent it from growing down the embankment into the water, and the ponds surfaces should be kept free of floating solids. Maintenance is facilitated, and embankments protected, by placing precast concrete slabs at the waterline or down the whole of the submerged slope. In Kenya, odours and mosquitoes were invariably present at ponds where weeds had been allowed to grow down the embankments into the pond contents, and scum allowed to build up on the liquid surface. Well maintained ponds, unless overloaded, were free from odours and insect nuisance.

The following table summarises contemporary comparative costs (20 K shs = 1£S) for treatment works built by contract in East Africa :

| One Mgal/d Unit | Conv. Filter | Ox. Ditch | Fac+Mat Pond | An+Fac+ Mat Pond |
|---|---|---|---|---|
| Acres | 10.0 | 7.75 | 45 | 35 |
| Cap. Cost sh. | 6M | 4M | 3.7M | 3.03M |
| Run. Cost sh. | 150000 | 180000 | 50000 | 50000 |
| Cap. Cost/gal. | 6.0 | 4.0 | 3.7 | 2.03 |
| Run Cost/gal. | 0.15 | 0.18 | 0.05 | 0.05 |

In India at that time, the cost of WSPS was reported to be less than 25 percent of that for conventional systems. The very low comparative costs for ponds in India is believed to be the result of highly labour intensive construction methods.

Embakasi Ponds

More information is available about the performance of these ponds than any other in Kenya. They originally consisted of a facultative pond, designed for a surface loading of 225 kg $BOD_5$/ ha d, followed by a maturation pond with approximately half the surface area. As the quantity of sewage supplied to the ponds increased, the surface loading rose to about 315 kg $BOD_5$/ha d and the facultative pond became completely anaerobic. Consequently a new, larger facultative pond was installed, creating a 3-pond series system and reducing the surface loading on the new primary pond back to about 225 kg $BOD_5$/ha d. This empirical loading cam e to be adopted as the MOW design criteria for facultative ponds in Kenya.

With an influent $BOD_5$ concentration of 400mg/l, the total BOD reduction through the 3-pond system was consistantly around 95 percent, with a final effluent concentration from 14 to 25 mg/l. By 1972 the influent BOD had risen to values between 450 and 500 mg/l with a surface loading of about 300 kg $BOD_5$/ha d. The pond system was again close to failure, but measurements of BOD and faecal coliform (Ref. 4) removals gave the following results :

| Sample | $BOD_5$ mg/l | Faecal Coliforms no/ml |
|---|---|---|
| Influent | 450 | $210 \times 10^3$ |
| Pond 1 effluent | 110 | $5.5 \times 10^3$ |
| Pond 2 effluent | 70 | 190 |
| Final effluent | 55 | 12 |
| Total Removal % | 88 | 99.99 |

The $BOD_5$ of the receiving stream at this time was about 100 mg/l.

Design Criteria

The author's survey examined critically the methods available for the design of anaerobic, facultative and maturation ponds in relation to the environmental and socio-economic conditions pertaining in Kenya. The following recommendations are based on this analysis, together with the author's field observations and the performance data from the Embakasi ponds.

1. Anaerobic ponds should be used for wastewaters with strengths in excess of 500 mg $BOD_5$/l and maximum permissible pond loadings should not exceed 400g.$BOD_5$/M3 d. The following minimum $BOD_5$ removals may be expected in anaerobic ponds in Kenya :

| | |
|---|---|
| 2 day retention | 50 percent |
| 3 day retention | 60 percent |
| 5 day retention | 70 percent |

2. The Marais and Shaw equation (Ref 5) based on first order kinetics, and developed for southern African conditions, should be used for the design of facultative ponds :

$$L_e = \frac{700}{2H+8} = \frac{L_0}{(1+Kt)}$$

Where $L_o$ and $L_e$ are the influent and effluent $BOD_5$ values (mg/l) respectively, H is the depth of the pond in metres, K is the first order BOD removal rate constant (Day - 1), and t is the hydraulic retention time in days from which the dimensions of the pond can be found. The most appropriate form of the Arrhenius equation for the variation of K with temperature is that proposed by Arceivala (Ref. 6) :

$$K_T = 0.30 (1.05)^{T-20}$$

where 0.30 is the value of K at 20°C, and $K_T$ is the value at any other temperature T. 1.05 is the temperature co-oefficient applicable to the treatment of domestic sewage in WSPs.

3. Marais and Shaw found that in order to obtain a satisfactory final effluent BOD it was necessary to provide two maturation ponds in series, each with a detention time of 7 days. They also found that the removal of faecal bacteria follows first order kinetics :

$$\frac{Ne}{No} = \frac{1}{(1+Kta)\ (1+Ktf)\ (1+Ktm)n}$$

where $N_o$ and $N_e$ are the influent and effluent bacterial concentrations respectively, and K is the bacterial decay rate (Day-1), $t_a$ $t_f$ and $t_m$ are the detention times in the anaerobic, facultative and maturation ponds respectively, while n is the number of maturation ponds. While K will vary with temperature (Ref. 7), it is advisable to adopt a conservative constant value of 2.0 for sanitary safety. $N_e$ should be less than 5000/100 ml. If this is not achieved with two 7 - day maturation ponds, or if a higher standard is required, then 3 maturation ponds in series each with a detention time of 5 days should be provided. Pond depths should be the same as the preceeding facultative pond.

## KANO, NOTHERN NIGERIA

The Kenya experience in sanitation is being repeated in Kano, and again the WSP will play an important part in the solution. The following quotations are taken from the recent Master Plan Report of the UNDP Sewerage and Drainage Survey of Kano (Ref. 8) :

> The lack of experience and skilled labour for operating a waterborne sewage disposal system, the frequent power failures and the foreign currency shortage and restrictions forbid highly sophisticated technical solutions and facilities. This applies mainly to wastewater treatment plants. Existing plants in Kano with artificial treatment processes either do not work or are kept running only with great difficulties. Therefore natural treatment will be proposed in the study.

and

> The tropic climate favours natural sewage treatment processes. Since the availability and cost of land is still not a limiting factor, wastewater treatment in ponds is the most economical solution.

Already a WSP is under construction to serve one of the new housing estates in Kano, ponds have been proposed for the new Bayero University and the UNDP consultants have proposed ponds in conjunction with afforestation irrigation, for the treatment of mixed domestic and industrial wastewaters.

Again the difficulty arises of selecting suitable design criteria in an area with a complete lack of empirical data. Here the Kenya experience is instructive. While the climate of Kano is generally much hotter and less humid than Kenya there are nevertheless many similarities :

a. Seasonal rivers with highly polluted dry weather flows

b. High strength (BOD and faecal pathogen) domestic sewage;

c. A large rural riparian population; and

d. A distinct cool season with temperatures similar to those in Nairobi.

### Recommendations

1. The above design criteria found appropriate for Kenya are recommended as a guide to the design of ponds in Northern Nigeria. However, these should be used in conjunction with an experimental programme to check the efficacy of the design, and the suitability and seasonal variation of the biological rate constants assumed.

2. Flow measuring devices should be installed at all major ponds. Without influent flow measurements it is difficult to determine actual loading rates and detention times, and without effluent flow measurements it is impossible to assess the combined losses due to evaporation and seepage in the pond system.

3. Ideally, a regular testing programme of both influents and effluents should be instituted at several ponds in different climatic zones, so that a body of performance data can be built up as an aid to future design in Northern Nigeria.

## REFERENCES


1. KENYA GOVERNMENT. Sectorial Study and National Programme for Community and Rural Water Supply Sewerage and Water Pollution Control. WHO. Brazzaville, 1972.

2. HUNT MA. and RESTONBERG HJW. Oxidation Ponds in Kenya. J.I.S.P., (3) 230, 1964.

3. FRASER JI. The Design of Waste Stabilization Ponds in Kenya. MSc Thesis, University of Newcastle Upon Tyne, 1975.

4. MARA DD. The use of Agar Dip-Slides for Estimates of Bacterial Numbers in Polluted Waters. Water Research, 6, 1605. 1972.

5. MARAIS GvR and SHAW VA. A Rational Theory for Design of Sewage Stabilization ponds in Central and South Africa. Trans. S. Afr. Instn. Civ. Engrs., 3, 205, 1961.

6. ARCEIVALA SJ et al. Waste Stabilization Ponds: Design, Construction and Operation in India, CPHERI, Nagpur, 1970.

7. MARAIS GvR. Faecal Bacterial Kinetics in Stabilization Ponds. J.E.E. Div., ASCE, 100 (EEI), 119, 1974.

8. KANO STATE GOVERNMENT, NIGERIA. Kano Sewerage and Drainage Project: Master Plan Report. UNDP, New York, 1978.