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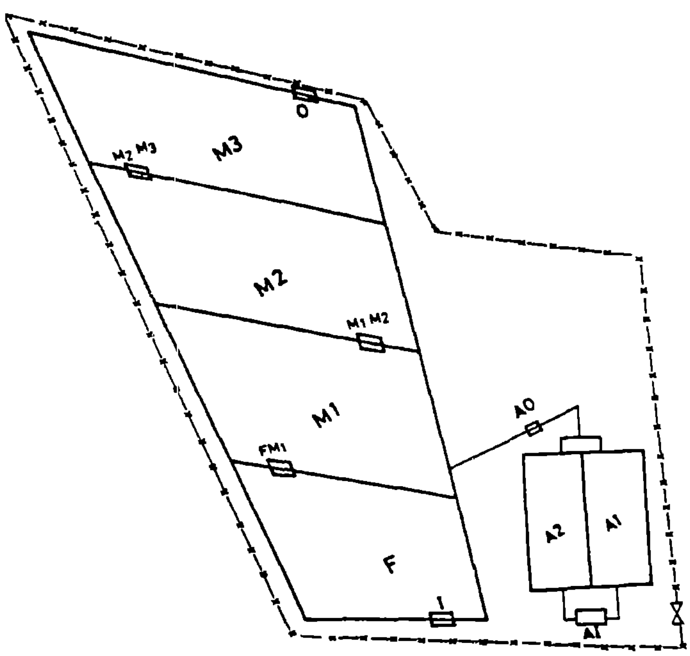
Evaluation of Vingunguti waste stabilization ponds treating municipal and industrial wastewaters



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EVALUATION OF VINGUNGUTI WASTE STABILIZATION PONDS TREATING MUNICIPAL AND INDUSTRIAL WASTEWATERS

by Ramadhani Mussa

Page

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ABSTRACT

This work is mainly based on the field and laboratory investigations done at Vingunguti waste stabilization ponds in Dar es Salaam, Tanzania. The ponds are treating domestic and industrial wastewater jointly. They consist of two anaerobic ponds in parallel, one facultative pond and three maturation ponds in series.

Details of the concerned industries were collected through questionnaires. Samples were collected twice per week from inlets and outlets of each pond unit during 11.11.1991 - 16.1.1992. The laboratory analyses included tests for biochemical oxygen demand (BOD_5), total dissolved solids (TDS), fecal coliforms (FC), fecal streptococci (FS), ammonia (NH_3-N), nitrate (NO_3-N), nitrite (NO_2-N), pH, copper (Cu) and chromium (Cr). These analyses were carried out at the water section laboratory of the Faculty of Engineering at University of Dar es Salaam.

More than 20 industries discharge their wastewaters into Vingunguti waste stabilization ponds. They include textile, printing paints, metal and chemical industries producing heavy metals and other toxicants that inhibit microbiological growth in ponds.

The total performance of the Vingunguti waste stabilization ponds was poor. Total removal efficiencies on BOD_5, TDS, NH_3-N, NO_3-N and NO_2-N were 48 %, 44 %, 19 %, 20 % and 51 % respectively. The total efficiencies in FC and FS reduction were 98.79 % and 98.83 % respectively.

The performance of the anaerobic ponds was the lowest, with BOD_5 reduction of only 7 %. NH_3-N was increasing by 3 % in the ponds and NO_3-N and NO_2-N removal was only 7 % and 17 % respectively. The poor performance of the anaerobic ponds may be due to sludge accumulation, short-circuiting or presence of illegally discharged industrial toxicants.

The facultative pond showed a slightly better performance. BOD_5 removal was 39 % and removals of NH_3-N, NO_3-N and NO_2-N were 4 %, 17 % and 47 % respectively. As the facultative pond is directly receiving industrial effluents, the low performance may be attributed to the adverse effect of the industrial toxicants. Highest reduction in FC and FS was observed in the facultative pond: 93 % removal of FC and 85 % removal of FS.

The maturation ponds were efficient in pathogenic removal only. Individual removal efficiencies in the three maturation ponds ranged 57 - 77 % for FC and 66 - 75 % for FS.

The treatment efficiency of the Vingunguti waste stabilization ponds may be revived by rearranging the order of flow in the ponds: all the wastewater (domestic and industrial) to flow first into anaerobic ponds, then into facultative pond and finally into maturation ponds. Pretreating industrial effluents at their source may also improve the situation.

1 INTRODUCTION

1.1 General

Treatment of wastewater is necessary to prepare it for safe, hygienic, nuisance free and environmentally sound discharge onto irrigated land surfaces or into receiving waters such as rivers, lakes and oceans.

Waste stabilization pond system is frequently the preferred wastewater treatment method particularly in tropical areas where the climate is favourable for biological treatment. High temperatures, intense solar radiation, long day-light hours and availability of low-cost land are the major factors that have made waste stabilization ponds to be used successfully in the tropics (Egbuniwe 1982). However, due to the complexity of the interactions of the treatment mechanisms in the ponds, the existing design methods have not been able to take into account all the factors influencing their operation.

Joint treatment of municipal and industrial wastewaters in waste stabilization ponds is increasingly regarded as environmentally and economically best way of handling the wastewater problem. Industries discharge an enormous variety of waste materials. Many industries produce toxic or non-biodegradable wastewaters while others produce readily biodegradable effluents that do not cause problems during treatment. Therefore, investigations on the behaviour of waste stabilization ponds treating combined municipal and industrial wastewaters are important for further improvement of the design methods and operational procedures.

1.2 Objectives of the study

The main objectives of this study were:

1) to assess the efficiency of Vingunguti waste stabilization pond system as a whole and the efficiency of the individual pond units

2) to study the effects of the various industrial effluents discharged into the ponds and recommend appropriate measures to be taken

3) to study the applicability of the design equations with the actual conditions

4) to give recommendations for future improvement of waste stabilization ponds treating combined domestic and industrial wastewaters.

1.3 Methodology and scope

The following approach was adopted during the thesis study:

1) Reviewing of available literature in journals, magazines, periodicals, research reports, text books and other relevant publications.

2) Collecting data and information from the Ministry of Water, Energy and Minerals, Dar es Salaam Sewerage and Sanitation Department, Howard Humphreys (Tanzania) Limited and management of various industries concerned. This included consultations and interviews with the authorities involved.

3) Field research study at the Vingunguti waste stabilization pond site. The study involved wastewater sampling from established sampling points at inlets and outlets of every pond unit. The samples were then analyzed in the laboratory. Some on-site analyzes were also done. Flow measurement was done by installing weirs at inlets and outlets of the ponds. Record of the number of trips made daily by truck emptiers was kept to enable estimation of loading into anaerobic ponds. Questionnaires were sent to various industries discharging effluents into Vingunguti ponds, asking for details on the different processes involved in production, quantity and quality of wastewater discharged and other relevant details.

2 WASTE STABILIZATION PONDS

Waste stabilization ponds are biological treatment units in which purification of the wastewater is done with the help of microorganisms. The types of microorganisms active in the purification process are determined by the composition of the wastewater and the conditions present in the treatment units.

2.1 Features and processes of waste stabilization ponds

Ponds are classified according to the nature of biological activity taking place within them. In these terms, stabilization ponds are classified as anaerobic, facultative and maturation.

2.1.1 Anaerobic ponds

These ponds are generally used for pre-clarification and are usually the first stage in a series of pond systems where heavily loaded wastewaters have to be treated (Karpe and Baumann 1980). Anaerobic ponds lack dissolved oxygen and the active microbial population comprises strictly anaerobic micro-organisms with a few traces of facultative micro-organisms. The organic material present in the influent is degraded by fermentative process (Horan 1990).

Anaerobic process

The anaerobic fermentation process converts waste organic materials to methane and carbon dioxide in the absence of molecular oxygen. Figure 1 shows a diagram of the metabolic steps involved in anaerobic digestion and interaction between the micro-organisms.

Legend:

1 fermentative bacteria
2 H_2-producing acetogenic bacteria
3 H_2-consuming acetogenic or homoacetogenic bacteria
4 CO_2-reducing methanogenic bacteria
5 acetoclastic methanogenic bacteria.

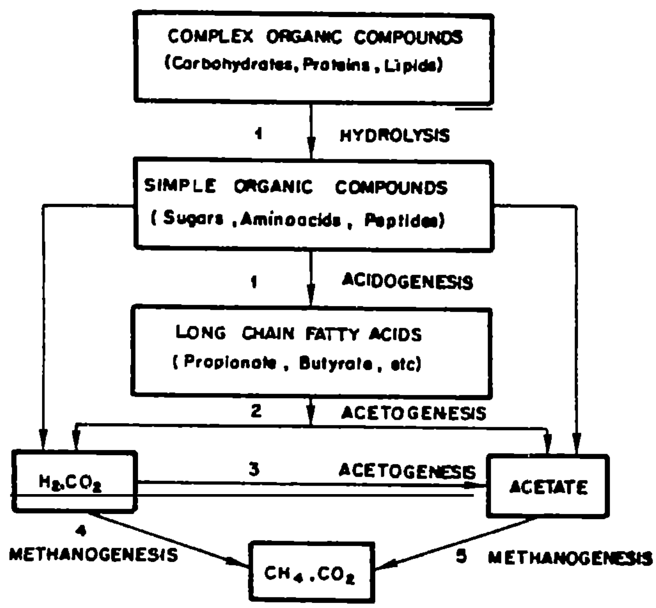


Figure 1. Metabolic steps involved in anaerobic digestion (Novaes 1986).

In the first stage the organic substrates are hydrolyzed, resulting in simpler compounds, through enzymes produced by fermentative bacteria. In the second stage, acidogenesis occurs with the formation of hydrogen, carbon dioxide, acetate and higher organic acids than acetate due to the activities of fermentative bacteria. The end-products such as butyric acid are extremely malodorous (Novaes 1986). The following reactions take place (Vigneswaran et al 1986):

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH \text{ (acetic)} + 2CO_2 + 4H_2 \quad (1)$$

$$C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH \text{ (butyric)} + 2CO_2 + 2H_2 \quad (2)$$

$$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH \text{ (propionic)} + 2H_2O \quad (3)$$

During the third stage, acetogenesis occurs and the organic acids produced are converted into hydrogen, carbon dioxide and acetate by the acetogenic bacteria. In addition, a part of the available hydrogen and carbon dioxide is converted into acetate by the homoacetogenic bacteria (Novaes 1986). The following reaction takes place (Vigneswaran et al 1986):

$$CH_3CH_2COOH \text{ (propionic)} + 2H_2O \rightarrow CH_3COOH + CO_2 + 3H_2 \quad (4)$$

$$CH_3CH_2CH_2COOH \text{ (butyric)} + 2H_2O \rightarrow 2CH_3COOH + 2H_2 \quad (5)$$

During the last stage, a group of methanogenic bacteria both reduces the carbon dioxide and decarboxylates the acetate to form methane (Novaes 1986). The reduction of carbon dioxide to methane by hydrogen-utilizing methane bacteria takes place through the following reaction (Vigneswaran et al 1986):

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (6)$$

The reaction during the conversion of acetic acid into a mixture of carbon dioxide and methane by acetoclastic methane bacteria is (Vigneswaran et al 1986):

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (7)$$

The resulting gaseous end-products are odourless and when they escape to the atmosphere they contribute to the process of BOD removal. About 70 % of the BOD removed in an anaerobic pond will be in the form of methane gas. Anaerobic ponds can therefore operate for many years without desludging (Horan 1990).

Methanogens are very sensitive to changes in pH value and they will only tolerate a pH of 6.2 - 8.0. If the rate at which volatile acids are produced exceeds the rate at which they are degraded by the methanogens, the pH will fall and the methanogens will be inhibited and ultimately killed. The growth rate of methanogens is thus the limiting step and determines the maximum organic loading to an anaerobic pond (Horan 1990).

Temperature can also affect methanogens. Their activity is very low below 10 °C, but increases rapidly as the temperature increases. Temperature is, therefore, an important factor for the calculation of the organic loading rate.

The other process involved in anaerobic ponds is sedimentation. This process provides an additional mechanism for the removal of BOD in form of suspended solids. The sedimented solids will undergo rapid anaerobic decomposition at the bottom of the pond. A well designed anaerobic pond can achieve up to a 60 % BOD-reduction depending upon the temperature and retention time (Horan 1990). Figure 2 shows the generalized curve for the removal of BOD and pathogens in relation to retention time.

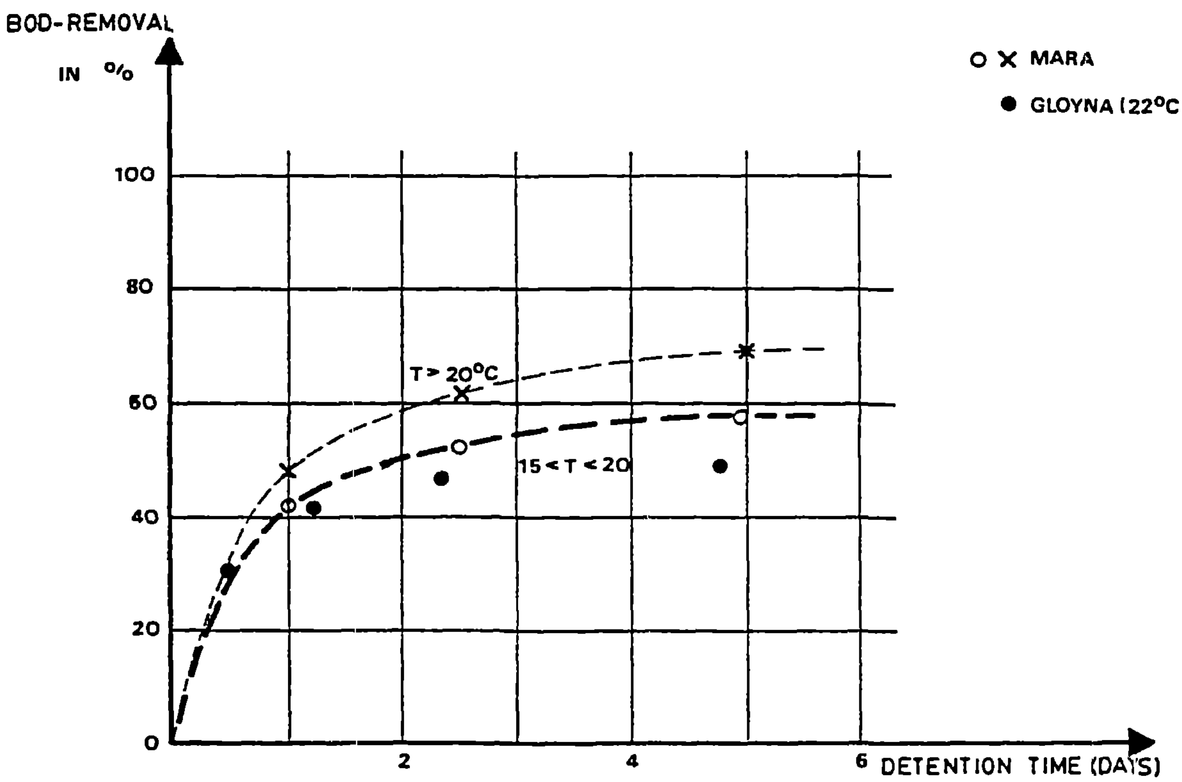


Figure 2. BOD removal in relation to temperature and detention time (Karpe and Baumann 1980).

When the sedimented organic material is degraded, a large amount of ammonia is released as ammonium. Due to lack of oxygen, nitrification can not occur and this ammonium leaves the pond in the effluent. The effluent from an anaerobic pond often contains up to 20 % more ammonium than is present in the influent.

Of particular importance in anaerobic ponds is the biological interconversions undergone by sulphur-containing compounds. The evolution of H_2S, which results from the anaerobic reduction of sulphate, is responsible for the odours associated with anaerobic ponds. The reaction proceeds according to the following equation:

$$CH_3COOH + SO_4^{2-} + 3H^+ \rightarrow 2CO_2 + H_2S + 2H_2O \quad (8)$$

This reaction is carried out by sulphate reducing bacteria and H_2S is the major end product (Horan 1990).

2.1.2 Facultative ponds

The major role of the facultative ponds is the removal of BOD. The ponds are characterized by three zones. In the upper regions, near the water surface, aerobic conditions prevail. At the bottom of the pond reduction occurs under anaerobic conditions. Between these two layers there is a facultative region, where a mixture of both reactions take place (Karpe and Baumann 1980).

Aerobic zone

The aerobic conditions at the surface of the pond are mainly due to the photosynthetic activity of the algae growing where nutrients and light are available. Like all plants, algae produce oxygen which is absorbed by the aerobic bacteria living in wastewater (Karpe and Baumann 1980). The bacteria consume oxygen in respiration and multiplication and, at the same time, they break down organic matter present in the wastewater. As a by-product of their metabolism, they release carbon dioxide, nitrogen and phosphate compounds which serve the algae as nutrients and as raw material for photosynthesis. Some of the oxygen is again used by the aerobic bacteria thus continuing the cycle (WHO 1987). The symbiosis between algae and bacteria is summarized in Figure 3.

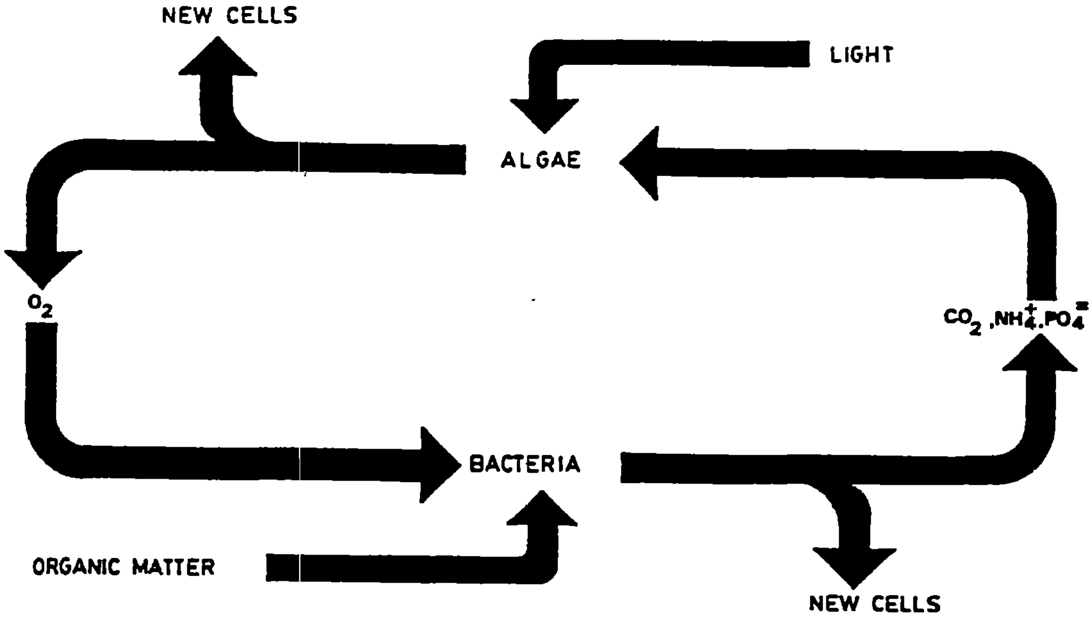


Figure 3. Symbiosis of algae and bacteria in stabilization ponds (Karpe and Baumann 1980).

The photosynthesis process depends on the light intensity. The algae population decreases with the depth of the pond and the proportion of oxygen diminishes correspondingly. In the facultative zone of the pond, water contains little oxygen and deeper in the anaerobic zone, it contains no oxygen.

Wind and heat are also determinants which control the function of the facultative ponds. Especially in the tropical zones, the upper water layer will heat up rapidly. Without the circulation of water caused by the activity of wind, a discontinuity in temperature at a depth of only 50 cm can occur. Some of the algae may sink down from the warm water region (above 35 °C), forming a light barrier. This phenomenon will immediately cut down the rate of photosynthesis and the production of oxygen. The pond will therefore "tip over" and become an anaerobic one (Karpe and Baumann 1980).

Anaerobic zone

During the retention period of the wastewater in facultative ponds, all solid substances form sediment at the bottom. Their anaerobic reduction takes place at temperatures above 15 °C, developing methane, carbon dioxide, and other anaerobic gases. Anaerobic metabolism in the pond sediment serves to degrade sedimented sludge and thus increases the times between desludging. Typically, desludging period for facultative ponds is 5 - 10 years (Karpe and Baumann 1980).

Facultative zone

This zone is characterized by all the processes taking place in the aerobic and anaerobic zones. In addition, facultative bacteria consume combined oxygen from nitrates and sulphates when free oxygen is exhausted. The stabilization process that takes place in a facultative pond is summarized in Figure 4. The effluent of a facultative pond taken from the surface layer is strongly green coloured due to the presence of algae. It also contains other living organisms such as microcrustaceans, bacteria and rotifers, and has a high content of dissolved oxygen. However, there are practically no suspended solids that will settle (WHO 1987).

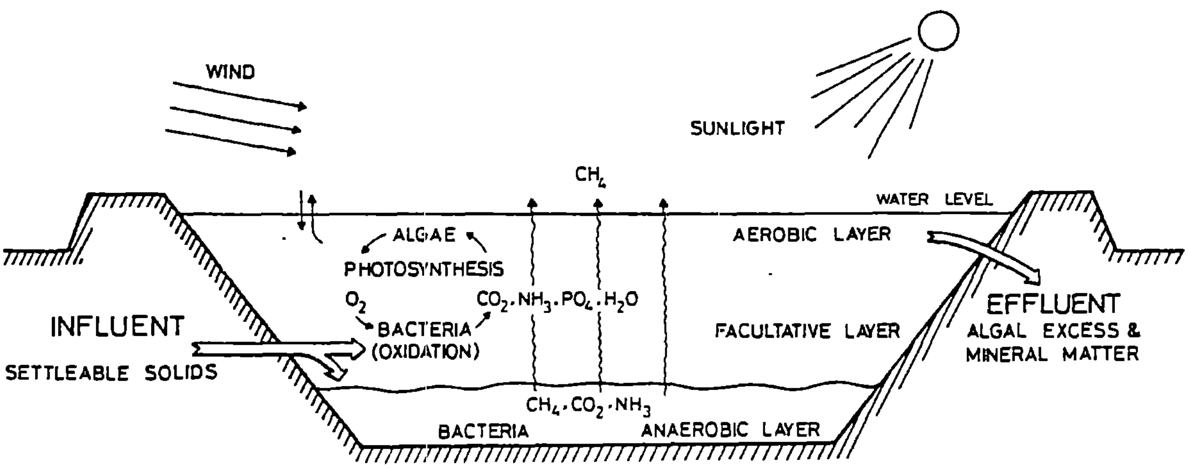


Figure 4. The stabilization process in a facultative pond (WHO 1987).

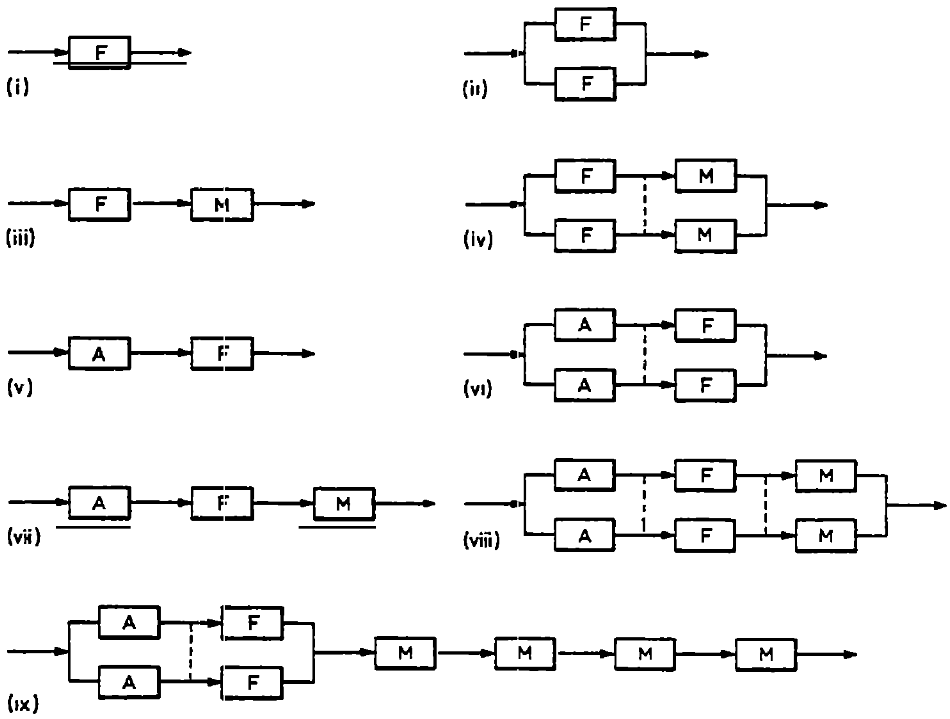
2.1.3 Maturation ponds

Maturation ponds are used mainly for reduction of pathogenic microorganisms such as viruses, bacteria and helminths. This is achieved by providing a retention time long enough (5 - 10 days) to reduce the number to the required level (Horan 1990). The bacterial effect of maturation ponds is due to several natural factors including sedimentation, lack of food and nutrients, solar ultra-violet radiation, high temperatures, high pH value, predators, toxins and antibiotics excreted by some organisms, and natural die-off (WHO 1987).

Suitably dimensioned maturation ponds reach a reduction of coliform bacteria of 99.99 % and a BOD-reduction of from about 60 mg/l to less than 25 mg/l. The ponds work under completely aerobic conditions and in general have a depth of 0.5 - 1.5 m (Karpe and Baumann 1980).

2.1.4 Pond combinations

The distribution of functions among the different pond types in a stabilization pond system means that two or more types of ponds should be connected in series to achieve better effluent quality. Figure 5 shows the possible pond arrangements in parallel and series.



Legend: A = anaerobic pond
F = facultative pond
M = maturation pond.

Figure 5. Different arrangements of ponds (WHO 1987).

2.2 Design principles

2.2.1 Design of anaerobic ponds

To attain anaerobic conditions in the pond, the production of oxygen by algal photosynthesis must be inhibited and the rate of oxygen utilization must exceed the rate of re-aeration at the surface. This is achieved by designing the pond as deep as practically feasible (up to 5 m or more) and ensuring a high organic loading rate (Horan 1990).

There are various procedures used for the design of anaerobic ponds, but all of them adopt one of the following criteria:

- surface loading rate (kg BOD_5/ha·d)
- volumetric loading rate (g BOD_5/m^3·d)
- hydraulic retention time (d).

Surface loading rate

For tropical regions, a pond is expected to be anaerobic all the time if surface loading is more than 1 000 kg BOD_5/ha·d.

Surface loading is defined as

$$L_s = L_i Q/10A \quad (9)$$

where L_s = surface loading (kg BOD_5/ha·d)
L_i = average influent BOD (mg O_2/l)
Q = average influent flow rate (m^3/d)
A = surface area of pond (m^2).

However, according to Gloyna (1971) cited by WHO (1987), surface loading is inadequate for sizing an anaerobic pond despite that it is still adopted by many designers.

Volumetric loading rate

The volumetric organic loading rate is defined as (Mara and Monte 1990):

$$L_v = L_i Q/V \quad (10)$$

where L_v = volumetric organic loading rate (g/m^3·d)
L_i = average influent BOD (mg O_2/l)
Q = average influent flow rate (m^3/d)
V = the required pond volume (m^3).

The required value of L_v is selected on the basis of the mean temperature of the coldest month. Table 1 gives the volumetric design loadings for anaerobic ponds and the corresponding BOD_5 removals.

Table 1. Design loadings for BOD_5 removals in anaerobic ponds (Mara and Monte 1990).

Design temperature °C	Volumetric BOD_5 loading g/m^3·d	BOD_5 removal %
< 10	100	40
10 - 20	20T - 100	2T + 20
> 20	300	60

T = design temperature

Retention time

Retention time is the most commonly used design parameter in anaerobic ponds. Gloyna (1971) cited by WHO (1987) has recommended a maximum retention time of 5 days in tropical areas. The relationship between retention time and BOD reduction is given in Table 2.

Table 2. BOD reduction in anaerobic ponds as a function of retention time (Mara 1976 cited by WHO 1987).

Retention time d	BOD_5 reduction %
1	50
2.5	60
5	70

Retention time is calculated as (Karpe and Baumann 1980):

$$t = AD/Q \qquad (11)$$

where t = retention time (d)
A = surface area of pond (m^2)
D = depth of pond (m)
Q = quantity of wastewater (m^3/d).

2.2.2 Design of facultative ponds

A series of possible procedures for the calculation of pond dimensions have been presented. The common empirical and kinetic approaches are McGarry and Pescod equation, Gloyna equation and Marais and Shaw first order reaction equation.

McGarry and Pescod equation

Surface loading is given by the following empirical formula (Mara and Pearson 1987):

$$L_{s,o} = 60.3(1.099)T \qquad (12)$$

where $L_{s,o}$ = the permissible surface loading (BOD_5/ha·d)
T = mean air temperature (°C).

The equation has later been subjected to various refinements as follows:

$$L_{s,o} = 20T - 120 \qquad (13)$$
$$L_{s,o} = 20T - 60 \qquad (14)$$
$$L_{s,o} = 10T \qquad (15)$$
$$L_{s,o} = 50(1.072)T \qquad (16)$$

All these equations give different loads for any given temperature. This has led many designers to prefer a kinetic approach (Mara and Pearson 1987).

Application of the McGarry and Pescod equation will result in an effluent BOD_5 of 50 - 70 mg/l (WHO 1987).

Gloyna equation

Gloyna's empirical equation presumes a BOD removal of 80 - 90 % and has the following form (Gloyna 1976 cited by Banerji and Ruess 1987):

$$V = 3.5 \times 10^{-5} Q L_u (1.085^{35-T}) f f' \qquad (17)$$

where V = pond volume (m^3)
Q = wastewater flow (l/d)
L_u = ultimate influent BOD (mg/l)
T = pond water temperature (°C)
f = algal inhibition factor
f' = sulphide or other immediate COD factor.

Marais and Shaw first order reaction equation

This kinetic approach involves the following basic equation (WHO 1987):

$$\frac{L_e}{L_i} = \frac{1}{1 + k_T t} \qquad (18)$$

where L_e = effluent BOD_5 (mg/l)
L_i = influent BOD_5 (mg/l)
k_T = breakdown rate at temperature T °C (d^{-1})
t = retention time (d).

The breakdown rate depends on pond temperature:

$$k_T = 0.3(1.05)^{T-20} \qquad (19)$$

where T = pond operating temperature (°C).

From equation 19, the formula for the calculation of pond area can be deduced as (Karpe and Baumann 1980):

$$A = \frac{Q(L_i - L_e)}{18 \cdot D(1.05^{T-20})} \qquad (20)$$

where A = pond surface area (m^2)
Q = wastewater flow (m^3/d)
D = pond depth (m).

The retention time (d) is given as (Karpe and Baumann 1980):

$$t = AD/Q \qquad (21)$$

The depth depends on the prevailing climatic conditions and varies 1.0 - 3.0 m (Table 3).

Table 3. Depth of facultative ponds in relation to environmental conditions and kind of sewage (modified from Karpe and Baumann 1980).

Recommended depth m	Environmental conditions	Type of wastewater
1,0	Uniform warm temperature	Presettled wastewater
1,0 - 1,5	Uniform warm temperature	Untreated wastewater
1,5 - 2,0	Moderate seasonal temperature fluctuations	Raw wastewater containing settleable solids
2,0 - 3,0	Wide seasonal temperature variations	Large amounts of settleable grit or settleable solids

2.2.3 Design of maturation ponds

The removal of fecal coliform bacteria from any pond follows a first order removal kinetics as follows (Horan 1990):

$$\frac{N_e}{N_i} = \frac{1}{1 + k_b t} \qquad (22)$$

where N_e = number of fecal coliforms in effluent
N_i = number of fecal coliforms in influent
k_b = bacterial die-off constant (d^{-1})
t = retention time in pond (d).

Yanez (1982) cited by WHO (1987) has compiled data for the values of die-off constant for fecal coliform bacteria and salmonella (Table 4).

Table 4. Values of die-off constant for different bacterial species (modified from Yanez 1982 cited by WHO 1987).

Organism	k_b d^{-1}	Temperature °C
Fecal coliforms	0.552	11-15
Fecal coliforms	0.664	16-29
Fecal coliforms	2.0	Not recorded
Fecal coliforms	2.6	20
Salmonella	0.8	Not recorded

For a number of ponds in series, the corresponding equation is (Horan 1990):

$$\frac{N_e}{N_i} = \frac{1}{(1 + k_b t_a)(1 + k_b t_f)....(1 + k_b t_m)^n} \quad (23)$$

where t_a, t_f, ...t_m = retention times of the anaerobic, facultative and maturation ponds in the series

n = the number of maturation ponds required.

k_b is sensitive to temperature and can be expressed as:

$$k_{b(T)} = 2.6(1.07)^{(T-20)} \quad (24)$$

Solution of the design equation for maturation ponds is a trial and error procedure as equation (23) contains two unknowns: the number of ponds and the size that each should be. It is recommended to have many small ponds than fewer large ones with the same total retention time. However, careful decision on the the minimum size of pond is required to prevent significant short circuiting (Mara and Pearson 1987).

2.3 Factors affecting operation of waste stabilization ponds

There are several factors which may, advantageously or adversely, affect the hydraulic and biological conditions of wastewater stabilization ponds. Some of these factors can be taken into account at the design stage whereas others are beyond the designer's and the operator's influence. Care in site selection and design can reduce the impacts of some factors.

2.3.1 Climatic factors

Once a pond system has been designed and constructed, its subsequent performance relies largely on climatic factors such as wind action, temperature, rainfall, sunlight and evaporation (Lumbers and Andoh 1985).

Wind

Wind action is useful as it influences the mixing within ponds, thus minimizing short circuiting and ensuring a reasonable uniform distribution of BOD, algae and oxygen. The depth of wind induced mixing in a pond depends largely on the distance the wind is in contact with the water. Mara (1972) cited by Munene (1984), has indicated that this distance (unobstructed) should be about 100 m for maximum mixing.

To facilitate wind-induced mixing, the longest dimension of the pond should lie in the direction of the prevailing wind. However, whenever possible, ponds must be sited downwind of the community, in case odour problems arise (Horan 1990).

Temperature

Temperature is an important factor influencing the performance of a waste stabilization pond. At higher temperatures, dissolved oxygen present in the pond is partly liberated to the atmosphere. At lower temperatures it remains in the pond longer.

Temperature affects photosynthetic oxygen production as well as other biological reactions. Optimum oxygen production for some species of algae is obtained at 20 °C, and limiting lower and upper values appear to be about 4 °C and 37 °C respectively (Gloyna 1971 cited by Mayo 1988).

The function of anaerobic ponds depends also on temperature. The right equilibrium between the methane and acid-producing bacteria will only be achieved if the water temperature is more than 15 °C (Karpe and Baumann 1980).

Rainfall

Rainfall will have some influence on pond performance and reliability. Retention time in ponds is reduced during periods of rainfall. Heavy showers may dilute the contents of shallow ponds, affecting the food available to the biomass. On a very hot day, rain may cool the surface layer. The anaerobic sludge will then appear floating on the surface and hence spoil the effluent. Simultaneously, the algal mats on the surface of the pond will be driven to the bottom. Rainfall may also add oxygen to a pond through its own dissolved oxygen and by increasing surface turbulence (WHO 1987).

Solar radiation

The intensity of solar radiation is an important factor for the generation of oxygen through algal photosynthesis. Facultative ponds rely on solar radiation and the parameter varies mainly with latitude. Clouds also reduce the available light to some extent but direct sunlight is not absolutely essential. The complex of 21 ponds at Lima, Peru, surveyed in 1979, is a clear evidence that stabilization ponds can function without direct sunlight. A blue sky is rather uncommon there, yet the ponds have shown to be operating under completely normal photosynthetic conditions (WHO 1987).

The bacterial mortality rate in ponds is also largely influenced by the inactivation power of solar radiation (Mayo and Gondwe 1989).

Evaporation

Intense evaporation may upset the ecological balance in stabilization ponds through the increase in the concentration of solids. The salinity and the concentration of organic matter may be increased to a point at which the osmotic balance of the cells of the aquatic microorganisms is disturbed. It may also cause undesirable reduction in depth of water and affect retention time. Evaporation rates up to 5 mm/d may be regarded as negligible. However, in hot arid regions evaporation may exceed 15 mm/d (WHO 1987).

2.3.2 Physical factors

These factors are generally related to design and therefore can be controlled.

Water depth

Stabilization ponds are normally operated at constant depth. Intense seepage and evaporation or some emergency withdrawal of pond contents may cause the water level to drop on occasions, causing problems. If the depth drops to less than 0.6 m, aquatic plants are likely to grow very quickly. A large part of the surface may become covered with weeds extending above the water level. As the penetration of sunlight will be impaired, pond efficiency may drop to an unacceptable level. In such a case, mosquito breeding may also occur (WHO 1987).

Water depth requirements are different for every pond type since the biological processes that take place in the ponds are different.

Short-circuiting

Short circuiting in ponds is a common problem especially in the deeper anaerobic ponds. It results in stagnant zones within a pond which can cause odours. It also reduces the effective pond volume for wastewater treatment. These effects can be minimized by proper choice of pond geometry and proper placement of inlet and outlet structures.

For anaerobic ponds, a rectangular surface area is recommended with a length to breadth ratio of less than 3:1. Facultative and maturation ponds are designed to approximate plug flow mixing, therefore higher length to breadth ratios (up to 15:1) are employed. The inlet and outlet structures should be placed at diagonally opposite corners (Horan 1990).

Seepage

A survey on the ground permeability at a proposed pond site is of great importance at the planning stage. This will provide information regarding the need for bottom lining. Ponds built in permeable soils should be lined to attain maximum discharge, especially if the effluent is to be used for agricultural purposes. Lining is also important in cases where groundwater needs to be protected from pollution (WHO 1987).

2.3.3 Chemical factors

The main chemical factors affecting pond performance are pH, toxic materials and oxygen.

pH

Both anaerobic and facultative ponds operate most efficiently under slightly alkaline conditions. Most organisms in ponds have a pH tolerance of 6.0 - 9.0 and optimum range of 7.0 - 8.0 (Abid 1983 cited by Mayo 1988). Methane fermentation in anaerobic ponds is affected by pH changes. Methanogens will only tolerate a pH range of 6.2 - 8.0 (Horan 1990). Industrial wastewaters are normally the causes for extremes of pH value in ponds. It is therefore recommended that they should be controlled at the source rather than introducing the complexity of pH adjustment at the influent to the ponds.

pH in the facultative ponds depends upon carbon dioxide concentration in the medium. Due to the presence of excess CO_2 produced by aerobic bacterial respiration during the night, pH value will be low in the morning hours. In the evening, pH value increases as a result of algae absorbing the major part of the CO_2 in solution (WHO 1987).

Toxic materials

The presence of toxic materials in industrial wastewaters affects the performance of waste stabilization ponds. Heavy metals, pesticides, detergents, wastes from antibiotic-producing industries and many other industrial wastewaters that inhibit biological treatment should be controlled at the source (Alabaster et al 1991).

Oxygen

Dissolved oxygen is the best indicator of satisfactory operation of a facultative or maturation pond. In a normally functioning facultative pond, super saturation of free dissolved oxygen at the surface and in the subsurface layers occur during the afternoon. The oxygen concentration may drop to less than 1.0 mg/l at dawn due to the presence of algae.

The aerobic surface layer prevents gases with odour problems, released from the anaerobic layer, from coming out of the pond. However, odour problems still occur from time to time in facultative ponds due to the development of blue green algae when water temperatures are high.

Odour problems may also occur as a result of anaerobic patches appearing on the surface of a pond when bottom temperatures rise rapidly above 22 °C (WHO 1987).

2.3.4 Wastewater flow and composition

Wastewater flow

Stabilization ponds are sometimes designed on the basis of hydraulic retention time, a parameter directly related to wastewater flow. In practice, the average flow rate is quite an adequate basis for design due to the relatively large volume of pond systems.

Wastewater composition

The design of stabilization ponds is directly related to wastewater characteristics which are influenced by the type of sewerage system and the contributing industries. Combined sewers convey a more dilute wastewater on rainy days whereas separate sewers are less sensitive to rainfall. Infiltration contributions, industrial and institutional discharges, dumping of septic tank sludge into the sewers and other circumstances often affect the wastewater composition.

Organic loading, in terms of BOD_5 or COD, is the most fundamental parameter used in design. Some parameters other than organic loading may be important where industrial wastewaters are present in the sewage. These will help the designer know if there is a need of providing pretreatment to protect the biomass in the pond system.

2.3.5 Characteristics of receiving waters

The pond effluent will either have to be disposed of somewhere (into a stream, lake, etc.) or is reclaimed for further use. The self-cleaning and dilution capacity of a receiving water under critical flow conditions should be known to determine the degree of treatment to be provided. Sometimes a heavily loaded primary pond may be sufficient, while in other cases several ponds in series are necessary as a better effluent quality is essential.

2.4 Operational problems of waste stabilization ponds

Inspite of their relative operational simplicity, problems can develop with stabilization pond systems which can cause a reduction in their efficiency, nuisance or damage. Many of the problems can be avoided or minimized by good design and the rest can be prevented by maintaining good operational control and providing routine maintenance. Following are the common problems that occur in stabilization ponds:

1) Development of algal scum on facultative and maturation ponds: Algal mats may sometimes accumulate on the pond's surface as a result of rapid growth of blue green algae. The algal mats reduce light penetration into the pond and they also produce odour problems as they decay. The scum layer may be broken up by means of water jets and it will sink to the bottom of the pond (Arthur 1983 and Munene 1984). Wang 1991 noted that high concentration of algae in effluents is a typical problem in symbiotic algae/bacteria systems of wastewater treatment. They often cause secondary pollution to receiving water bodies.

2) High vegetation growth on embankments: Normally the pond embankments have a protective grass cover to prevent them from being eroded by wind and wave actions. However, when the grass is left to grow uncontrolled, burrowing animals like moles and rats may invade the area and affect the safety of the embankments. Therefore the grass cover should always be cut short (Munene 1984).

3) Mosquito nuisance: Mosquitoes create problems around waste stabilization ponds. A poorly maintained pond with a lot of growing weeds or scum provides a breeding site for mosquitoes. Regular cleaning of vegetation and removal of scum is necessary to control insects (Munene 1984).

4) Odour problems: Odour problems may arise from a number of situations. Odours can be caused by the nature of the wastewater itself and also by the anaerobic conditions in the pond. Hydrogen sulphide, which is the major compound produced by sulphur reducing bacteria, is responsible for odour problems in ponds. The best way to prevent the problem is to control industrial effluents. Another major source of odour is ammonia which originates from the conversion of urea to carbon dioxide and ammonia (Henry and Gehr 1980).

5) Overloaded ponds causing poor effluent quality and odour nuisance. Al-Salem and Lumbers (1987) have reported a significant reduction in the efficiency of Alsumra waste stabilization ponds in Jordan due to overloading. The reduction of BOD through the facultative ponds was found to be about 18 % only. The poor performance was attributed to the predominantly anaerobic conditions observed in most of the facultative ponds. The loading to the ponds was greater than that likely to lead to facultative behaviour.

3 COMBINED MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT IN WASTE STABILIZATION PONDS

3.1 Characteristics of wastewater

The most frequently used characteristic parameters of wastewater are (Pujol and Lienard 1990):

- Suspended solids (SS) and its organic fraction, volatile suspended solids (VSS) which characterize the particular type of pollution.

- The chemical oxygen demand (COD) and the biochemical oxygen demand in 5 days (BOD_5) which quantify the organic content of the wastewater. COD indicates the total organic content while BOD_5 indicates the biodegradable organic content.

- Forms of nitrogen (N) and phosphorus (P). These are fertilizing elements whose discharges are likely to accelerate the eutrophic processes.

- The pH and conductivity, which give a good indication of the water ionicity.

- Fecal coliforms, which indicate the risk of infection by pathogenic microorganisms.

- Heavy metals and inorganic salts, which indicate industrial pollution.

3.1.1 Domestic wastewater characteristics

The characteristics of domestic wastewaters are linked to their origin. There are:

- sewage water from toilets which contains essentially organic matter

- domestic wastewater from kitchens, bathrooms, etc. The daily discharge can vary considerably depending on the extent of the equipment and the hygienic habits such as showers or baths. These wastewaters contain, principally, organic matter as well as household products such as detergents and phosphates (Pujol and Lienard 1990).

The characteristics of municipal wastewater depends on original concentration in water supply, water usage and per capita consumption. Thus the characteristics vary from one locality to another and even from season to season within the same locality (Yayehyirad 1984). The typical characteristics of domestic wastewaters in small communities are given in Table 5.

Table 5. Characteristics of domestic wastewater in small communities (Pujol and Lienard 1990).

Parameter	Concentration g/capita·d
COD	75-80
BOD_5	30-35
SS	25-30
$N\text{-}NH_4^+$	8-9
$P\text{-}PO_4$	3.5-4

BOD_5 and COD concentrations confirm the organic nature of the domestic wastewater. The COD/BOD ratio, which is slightly greater than 2, indicates the biodegradable nature of such water (Pujol and Lienard 1990). Treatment of municipal wastewater can, therefore, be easily performed in biological treatment units like stabilization ponds.

3.1.2 Industrial wastewater characteristics

Depending upon the processes involved in an industry, there is a wide variation in wastewater composition from one type of industry to another. In this chapter, discussion is made on seven types of industries commonly found in Tanzania: textile industry, tanning industry, food processing industry (fruit and vegetable canning), metal industry (pickling, plating and sheet milling), chemical industry, breweries and dairies. Selection of these industries has taken into consideration the relevance of the discussion to the forthcoming chapters.

Textile industry wastewaters

Many substances present in textile effluents influence COD, some increasing it and others depressing it. Some substances will affect BOD, suspended solids content and pH. Some organic compounds will be difficult to destroy by biological oxidation since they generally have a low BOD. These are said to be biologically hard. Those that are readily oxidized are termed soft and usually have a high BOD. However, most of the organic compounds used in or extracted during textile processing are biodegradable to some degree. In the absence of toxic materials, therefore, the biological process can be successfully used for the purification of textile effluents (Yayehyirad 1984).

A typical example is from effluents of selected textile industries in Tanzania. Textile mill operations in Tanzania, generally, consist of weaving, dyeing, printing and finishing. The wastewaters from the textile mills contain a variety of chemicals such as inorganic salts, organic acids, starch, hydrogen peroxide, detergent alkalis, urea and also waste products from a big number of different dye-stuffs. Textile wastewaters are usually coloured, highly alkaline, contain high BOD and suspended solids and have high temperatures (Mashauri et al 1990). Table 6 shows the typical characteristics of textile effluents.

Table 6. Characteristics of textile effluents (modified from Germirli et al 1990).

Parameter	Unit	Concentration
BOD	mg/l	750
TSS	mg/l	240
COD	mg/l	2 000
Colour	mg Pt/l	2 000
pH	-	6.9

Tannery wastewaters

The major sources of pollutants in tannery industry are (Gathuo 1984):

- the constituents of the raw hide which are necessarily removed or adapted during the leather making process including hair substances, various proteins and natural fats of the hides together with any curing agents which may be utilized
- the chemicals employed in leather production, either present as surplus in their original form or converted into other products
- miscellaneous pollutants arising from housekeeping in tannery, for example machine washing and other sanitary activities.

The common pollutants and their minimal amounts resulted in during the production of chrome tanned leathers are given in Table 7.

Table 7. Tannery effluents characteristics (modified from UNIDO/UNEP 1975 cited by Gathuo 1984).

Content	Concentration mg/l
BOD	800
SS	650
Chrome	43
Sulphide	50
N	136

As the raw material of the tanning industry is a natural product, its soluble impurities are generally readily biodegradable and represent a large part of the BOD load in the effluent. The process chemicals employed are a variety of inorganic and organic materials, affecting total solids, pH and COD. Of particular importance are the appreciable quantities of sulphide and chromium that are present. These substances have proved to have significant effects on the performance of stabilization ponds (Yayehyirad 1984).

Fruit and vegetable canning industry wastewater

Wastewater is normally generated during washing and rinsing, peeling, blanching and processing. Washing and rinsing is done to remove soil, microbial contamination, leaves or stems and to remove solubles and insolubles after cutting, coring, peeling or blanching. Washing and rinsing operations constitute a major source of wastewater. The volume of water used in these operations may be up to 50 % of the total usage (Gilde and Aly 1976).

Peeling operations produce wastewater containing large quantities of suspended matter primarily organic in nature. Blanching is done to expel gases from vegetables, to whiten beans and rice and precook them, to inactivate enzymes that cause undesirable flavour or colour changes in food and to prepare products for easy filling into cans. Little fresh water is added to the blanching operation, therefore the concentration of organic materials is high due to leaching out of sugars, starches and other soluble materials from the product that is blanched. Although small in volume, wastewater from blanching operation is usually highly concentrated with dissolved and colloidal organic matter (Gilde and Aly 1976).

The final major sources of wastewater are from washing equipment, utencils and cookers. Also from washing of floors and general food preparation areas.

Metal industry wastewater

The metal industries dealt with in this chapter are secondary mills involved with finishing operations, such as pickling, plating and sheet milling.

Pickling is a process of chemically removing oxides and scales from the surface of the steel. This is done using water solutions of inorganic acids such as sulphuric, hydrochloric, nitric and phosphoric acids. After pickling, the steel passes through rinse tanks. The sources of wastewater from pickling operations are the strong spent acid solutions and the rinse water (Bramer 1976).

Metal plating consists of coating the finished metal product with a thin sheet of another metal for protective or decorative purposes. Processes in this operation include cleaning in alkaline solutions, rinsing, pickling, melting, chemical treatment and oiling. Wastewaters generated in plating industries include rinse water and concentrated process solutions. The metal content of the effluent commonly includes tin, chromium, zinc, copper and nickel, cadmium, aluminium and iron (Longhurst and Turner 1987).

In the sheet and strip mills, slabs are rolled with a continuous hot-strip mill. The slabs are brought to rolling temperature in continuous reheating furnaces. The conditioned slabs are then passed through scale breakers and high-pressure water sprays dislodge the loosened scales. Cooling water is then sprayed and the finished strip is coiled. The sources of wastewater in the sheet and strip mill operation is the cooling water and the sprayed high pressure water (Bramer 1976).

Chemical industry wastewater

Most of the highly pollutional wastewaters from chemical industries originate from process areas. This includes water formed or eliminated during reactions, wash-waters from cleaning operations, stem condensate from stripping operations and accidental losses due to spills and careless operation.

Process wastewaters may contain a variety of constituents including a portion of the feed-stock chemicals, products, by-products, side products and spent catalysts. Acidic and alkaline discharges are the characteristics of most chemical industries (Parsons 1976).

Brewery wastewater

The production of beer has two stages, malting of barley and brewing to beer from the malt. Brewery wastes are composed mainly of liquor pressed from the wet grain, liquor from yeast recovery and washed water from the various departments (Arellano 1987).

The major components of brewery wastewater are BOD and suspended solids which are produced in the brewhouse, during fermentation stage and during the bottling stage. The variations in brewing tradition and household practice are reflected in the effluent BOD values which are normally in the range of 0.8 - 2.5 kg/m^3 (Henze 1983). The typical breweries wastewater production and composition are given in Table 8.

Table 8. Characteristics of effluents from breweries (modified from Henze 1983).

Content	Concentration mg/l
SS	1 500
VSS	900
Total BOD	1 500
Soluble BOD	500
Total COD	2 000
Soluble COD	650
Total N	30
Total P	5

Dairy products wastewater

Processing and manufacturing of dairy products are water intensive operations both during product preparation and manufacturing. Maintenance of sanitation within the process area also uses a lot of water. This results in a problem in treatment and disposal of the large volume of wastewater generated. Dairy wastewaters contain phenolic substances which are supposed to be free from toxic substances. Phenols come from flavouring and from phenol sanitizing rubber boots used by workers in the processing area. Other contents include BOD, SS, nitrogen sulphur, grease and oil (Table 9) (Diaz 1987).

Table 9. Dairy products wastewater characteristics (Diaz 1987).

Parameter	Unit	Average concentration
BOD_5	mg/l	695
Suspended solids	mg/l	215
Grease and oil	mg/l	117
pH		11
Total solids	mg/l	1 480
Nitrogen	mg/l	0.95
Phosphates	mg/l	0.11

3.1.3 Characteristics of combined wastewater

Industrial wastewaters contain materials having a wide range of different characteristics. In most cases industrial effluents are composed of toxic or non-biodegradable materials. However, it is not uncommon to find industrial effluents that closely resemble domestic sewage and are therefore suitable for biological treatment. Some industrial effluents can be effectively treated by mixing with domestic sewage to improve the nutrient balance of the waste and to dilute the toxic compounds present (Alabaster et al 1991).

Generally, industrial wastewaters may be:

- non-harmful at all to treatment
- harmful to treatment processes
- harmful to sludge utilization
- useful to treatment processes

or a combination of the above when combined with municipal wastewaters.

3.2 Advantages of combined wastewater treatment

The easiest and most effective way of dealing with trade effluents is to admix it with domestic sewage. However, there are limits to the type of effluent which should be accepted. For example, the discharge must not contain substances which alone or in combination will inhibit the biological processes of biological treatment (Holding 1990).

The performance of stabilization ponds which are treating a mixture of domestic and industrial wastewaters can be put at risk by the presence of hazardous chemicals in the industrial wastewater fraction. Effluents from food processing industries, which comprise readily biodegradable organic matter are relatively easy to treat. In contrast, heavy metals from metal industries, such as copper, zinc, nickel, lead, cadmium and chromium can react with the microbial enzymes to retard or completely inhibit metabolism (Yayehyirad 1984).

Because of their comparatively long retention time, stabilization ponds allow a greater buffering capacity against shock loads of toxic material and a longer period for the biologically hard compounds discharged from industries. Other biological treatment systems such as activated sludge and trickling filters have shorter retention times and hence lack this advantage (Arthur 1983).

High strength industrial wastewaters with BOD loading in the range of 10 000 - 30 000 mg BOD/l can be treated by employing anaerobic ponds as pretreatment units. However, anaerobic processes are susceptible to inhibition by excess of sulphide as hydrogen sulphide. The sulphate loading rate should be kept below 500 mg SO_4^{2-}/m^3 d (Mara and Pearson 1987).

Oil and grease from industries can be well trapped in anaerobic ponds that have subsurface effluent offtake. The oil and grease are thus prevented from reaching facultative ponds and are gradually degraded in the anaerobic ponds.

In the case of textile effluents, joint treatment with municipal sewage can be considered to be the best alternative. By combined treatment, especially if textile wastewaters form one quarter or less of the total volume, many difficulties are solved. Flow, alkalinity and temperature extremes and fluctuations can always be corrected. Also decoloration is done more efficiently (Grau 1991).

Textile effluents are normally deficient in nitrogen and phosphorus and therefore it becomes necessary to add nutrient materials, like ammonium sulphate, to restore the balance before any biological treatment is given. This is why it is preferable to treat these effluents in admixture with municipal sewage which will supply the required nitrogen and phosphorus (Yayehyirad 1984 and Grau 1991).

The soluble impurities from tanning industry are generally readily biodegradable and therefore they can be effectively and cheaply treated in waste stabilization ponds together with domestic sewage. The problem of high concentration of chromium can be taken care of in anaerobic ponds and facultative ponds arranged in series. This has been proved by the performance of Nakuru waste stabilization pond system in Kenya. The average concentration of chromium in the raw sewage was found to be 1.58 mg/l. Approximately, 20 % of this was removed in the anaerobic ponds with a further 48 - 60 % removed in the first facultative pond. The second facultative pond removed a further 12 - 24 % and levels were undetectable in the effluents from the third pond (Alabaster et al 1991).

3.3 Limiting substances in combined wastewater treatment

Following is a list of the common substances which could create difficulties in biological treatment units. The list serves to illustrate the kind of problems associated with treating industrial discharges together with domestic sewages (Holding 1990).

<u>Acids and alkalis</u>: The optimum pH range for the biological treatment of sewage is around 6.5 - 8.0. Any acid or alkaline discharge which causes the pH of the mixed sewage to fall beyond the range will require neutralization before discharge.

<u>Non-ferrous metals</u>: Non-ferrous metals such as cadmium, chromium, copper, lead, mercury, nickel and zinc, have an inhibiting effect on biological processes. When their sludges are reused for agricultural purposes, they may inhibit crop growth, be assimilated by the plant and enter the food chain.

<u>Oils and fats</u>: These substances are a common occurrence in industrial wastewaters. They can inhibit atmospheric oxygen which is vital for biological wastewater treatment.

Pesticides and detergents: These are non-biodegradable compounds that can kill the bacteria present in the ponds.

Sulphates and sulphides: Excess of sulphides as hydrogen sulphide inhibit the anaerobic processes in ponds.

Additional problems occur if the industrial effluents contain substances with unknown environmental consequences. The damage may be done before the potential is even realized. For example local farmers used dried sewage sludge for soil conditioning until severe damage was noticed on a crop of pyrethrum. When the sludge was analyzed, trichlorobenzoic acid was discovered at a concentration of just one part in 100 M, but still a sufficient amount to damage the crop (Holding 1990).

3.4 Need of pretreatment

The most important objective of pretreating industrial effluents is to prevent problems in the sewerage system and with any of treatment processes employed (Upstone 1990).

Each industry is to some extent an individual case, therefore thorough study should be done to be able to characterize the effluents from a particular industry and propose pretreatment possibilities. Thorough investigations are important on the water balance, the processes involved, chemicals used, level of housekeeping and management of water and wastewater for each industry (Rantala 1987).

Pretreating textile effluents

The presence of colour in textile wastewaters is a common problem. The dyes are, in general, biologically non-degradable or slowly degradable. These would consequently lead to a very high turbidity in facultative ponds, limiting light penetration, and thus limiting algae growth. Inspite of the positive features of the combined treatment, in many cases the effluent is still coloured. It is practically impossible to estimate beforehand decoloration efficiency of joint treatment. Even pilot experiments do not guarantee perfect prediction of decoloration. Permanent changes of palette, types of dyes and fibres introduce unpredictable stochasticity. Flexible pretreatment for textile effluents is thus a necessity (Grau 1991).

Pretreating tannery effluents

Tannery discharges have high sulphide content (up to 40 mg/l). When these discharges pass through to the facultative ponds they result in the inhibition of photosynthetic algae. The pond water frequently turns bright pink due to profuse growth of purple photosynthetic bacteria which utilize sulphide. They convert the sulphide to elemental sulphur and deposit it within the cell. The profuse growth of the sulphur bacteria results in a high turbidity in the ponds. Light penetration and hence photosynthetic oxygen production is thus limited.

Alabaster et al (1991) have reported on the poor performance of the stabilization pond system in Nakuru, Kenya due to high sulphide levels in the raw sewage. It is probable that if the tanneries were to install a pretreatment facility for sulphide recovery, then a sufficient improvement in performance of the ponds would be seen. Pretreatment is also required to reduce the high amount of chromium present in tannery wastewater.

The common pretreatment activities include:

- Lowering the concentration of SS: This is a mechanical pretreatment for capturing suspended solids such as short fibres from a textile industry.

- Grease and oil removal: Grease and oil are usually lighter than water and may be separated by passing the wastewater through an interceptor or grease trap. The interceptor consists of a tank divided into compartments in which the grease and oil float to the surface of the wastewater and is retained by baffles.

- Cooling: Large volumes of hot industrial wastewaters may be cooled using cooling towers or spray ponds.

- Neutralization: Wastes with low pH value may be corrected by addition of an alkali. Usually, there is a choice of alkalis, some of which may produce a precipitate and hence require a subsequent settling stage. The most common alkalis used are sodium hydroxide and sodium carbonate. Highly alkaline wastewaters are neutralized by inorganic acids such as hydrochloric or sulphuric acid.

- Screening: This is designed to remove large floating and suspended solids by passing wastewater through racks or screens before it enters into a tretment plant. Screens may take the form of bars, wires or perforated plates. Collecting the solids from the screens can be done by mechanically operated rakes. Screening reduces the solids loading on subsequent treatment system. Sreening is particularly important for food processing and textile industries (Gilde and Aly 1976 and Diaz 1987).

- Grit removal: This is employed to remove smaller and more dense solids like sand and cinders. Metal industries and building construction firms normally produce this type of wastes. Grit removal may be done through channels and washing collections either by hand or mechanically. Removed grit is typically land filled (Diaz 1987).

4 VINGUNGUTI WASTE STABILIZATION PONDS

4.1 Background and location

Vingunguti waste stabilization ponds are located in Ilala district in Dar es Salaam region. They can be approached by using Pugu road or Uhuru street from the Dar es Salaam city centre. The ponds are about 12 km from the city centre and about 200 m north-west of TAZARA (Tanzania Zambia Railway Authority) railway station (Figure 6).

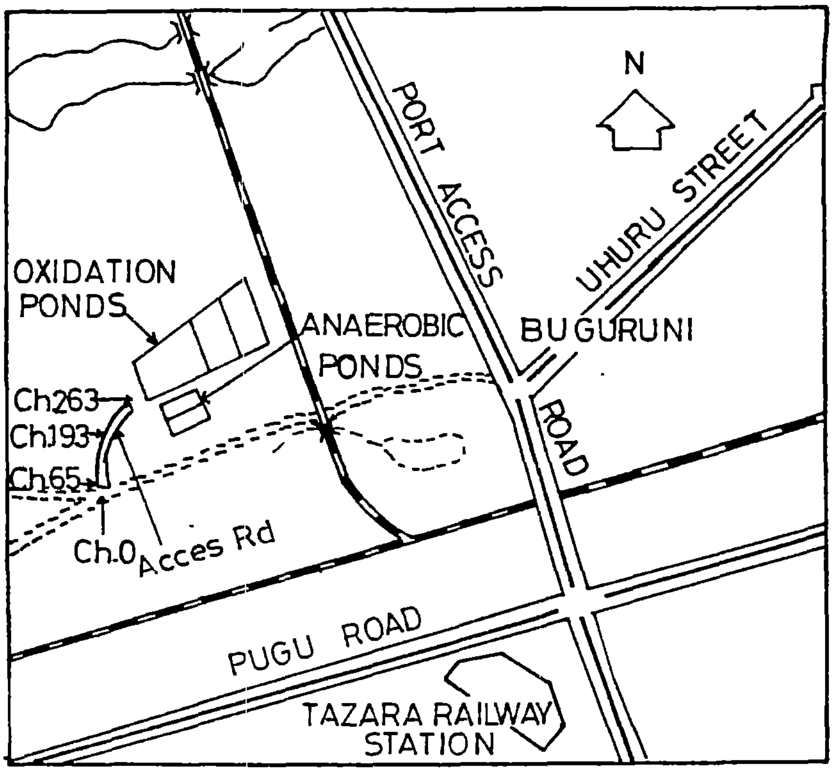


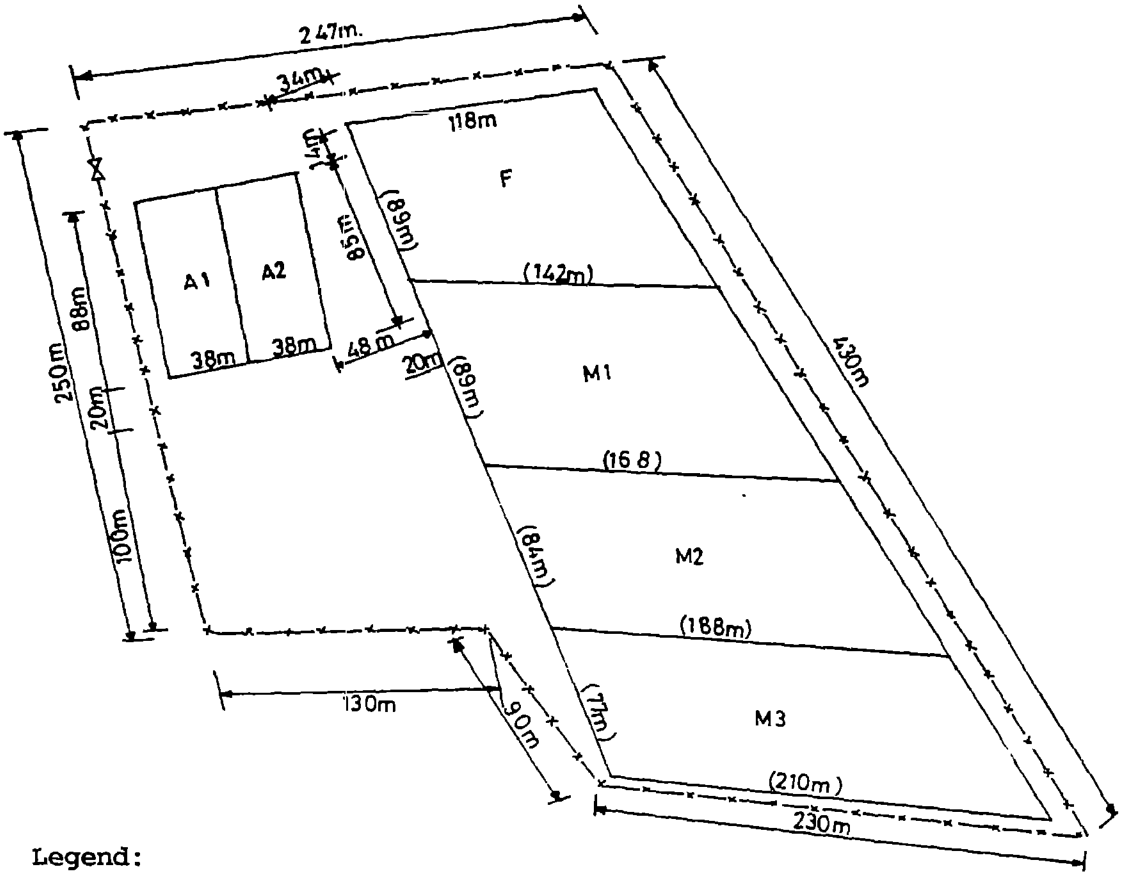
Figure 6. Location map of Vingunguti waste stabilization ponds (Howard Humphreys 1988).

The ponds started operation in 1976, a time during which only industrial wastewaters from Pugu Road industrial area were treated. At the beginning there were only four ponds; the first being facultative and the remaining three maturation.

In 1986 rehabilitation work began due to poor performance of the ponds which resulted from poor maintenance. The rehabilitation work consisted of constructing a dumping station (three chambers) to receive domestic wastewater from pit latrines and septic tanks carried by truck emptiers. Two anaerobic ponds were also added to treat the domestic wastewater. These additional units started to operate in February 1990.

4.2 Physical layout

Vingunguti waste stabilization ponds consist of six ponds: two anaerobic ponds (A_1 and A_2) in parallel, one facultative pond (F) and three maturation ponds (M_1, M_2 and M_3) connected in series (Figure 7).



Legend:

A_1, A_2 = anaerobic ponds
F = facultative pond
M_1, M_2, M_3 = maturation ponds.

Figure 7. Layout plan of Vingunguti waste stabilization ponds (Howard Humphreys 1988).

Combined treatment of domestic and industrial wastewater in the ponds begins at the first maturation pond. This pond receives wastewater from facultative and anaerobic ponds that receive industrial effluents and domestic sewage respectively. The final effluent from the ponds is discharged into Msimbazi River which flows to the Indian Ocean.

According to Howard Humphreys (1988), the anaerobic ponds have been designed to treat domestic wastewater from Temeke area which serves about 12 500 pit latrines and 600 septic tanks. However, physical observations showed that truck emptiers (Figure 8) collect wastewater (domestic) from other areas of the Dar es Salaam city too. They also collect industrial wastewater from some nearby industries which have not been connected to any sewerage system.

Figure 8. A truck emptier discharging wastewater into a chamber at Vingunguti waste stabilization ponds.

4.3 Design criteria used

This chapter gives a short description of the formulas and design criteria used for Vingunguti waste stabilization ponds. The design parameters used are given in Table 10.

Table 10. Design parameters used in the design of Vingunguti waste stabilization ponds (Howard and Humphreys 1988).

Parameter	Unit	Value
Influent flow to ponds A_1 and A_2	m^3/d	120
Influent flow to pond F	m^3/d	1762
Influent flow to ponds M_1, M_2 and M_3	m^3/d	2002
BOD5 load in ponds A_1 and A_2	g/ha·d	50
BOD5 reduction in ponds A_1 and A_2	%	70
Temperature	°C	25
Effluent BOD_5	mg/l	< 5
Effluent FC	no./100 ml	< 437

For the design of the two anaerobic ponds, equation (11) was used:

t = 5 d
D = 3 m
BOD reduction = 70 %
Q = 120 m^3/d for each pond.

For the design of the facultative pond, equation (20) was used:

A = pond area required (m^2)
Q = 1762 m^3/d
L_i = 400 mg/l
L_e = 60 mg/l
D = 1.3 m
T = 20 °C

For the design of maturation ponds, equation (22) was used to check the bacteriological quality of the pond contents:

N_i = 4×10^7 FC counts/100 ml
N_e = 5×10^3 FC
k_b = 3.1 d^{-1}
t = 7 d/pond

Using the above design formulas and criteria, the geometrical dimensions and hydraulic characteristics of the ponds were determined (Table 11).

Table 11. Dimensions of Vingunguti waste stabilization ponds (Howard and Humphreys 1988).

Pond	Retention time d	Depth m	Volume m^3
A_1	5.00	3.00	600
A_2	5.00	3.00	600
F	7.08	1.30	12 480
M_1	6.66	1.15	13 340
M_2	7.57	1.10	15 154
M_3	7.08	1.00	14 175

4.4 General observations

Observation during the study period showed that generally the ponds were well taken care of by the attendants. Grass was cut short regularly on the embankments and the paving slabs on the banks of the ponds were all in place (Figure 9). A few species of duck and other birds thrive in the last two maturation ponds indicating that the water in those pond units was cleaner than in the preceding ponds.

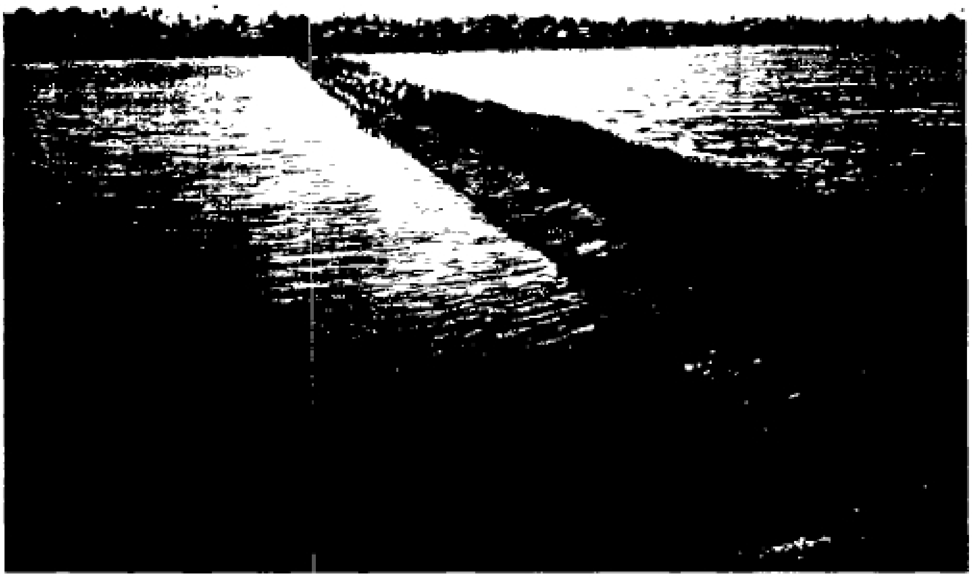


Figure 9. A view showing the facultative and maturation ponds. The paving slabs on the embankments are well in place and the grass has been cut short.

However, the following negative aspects were noticed:

- Scum accumulated at the corners of the ponds especially anaerobic ponds which also possessed strong smells. Layers of thick mats were found in anaerobic ponds which, however, were removed after some days (Figure 10).

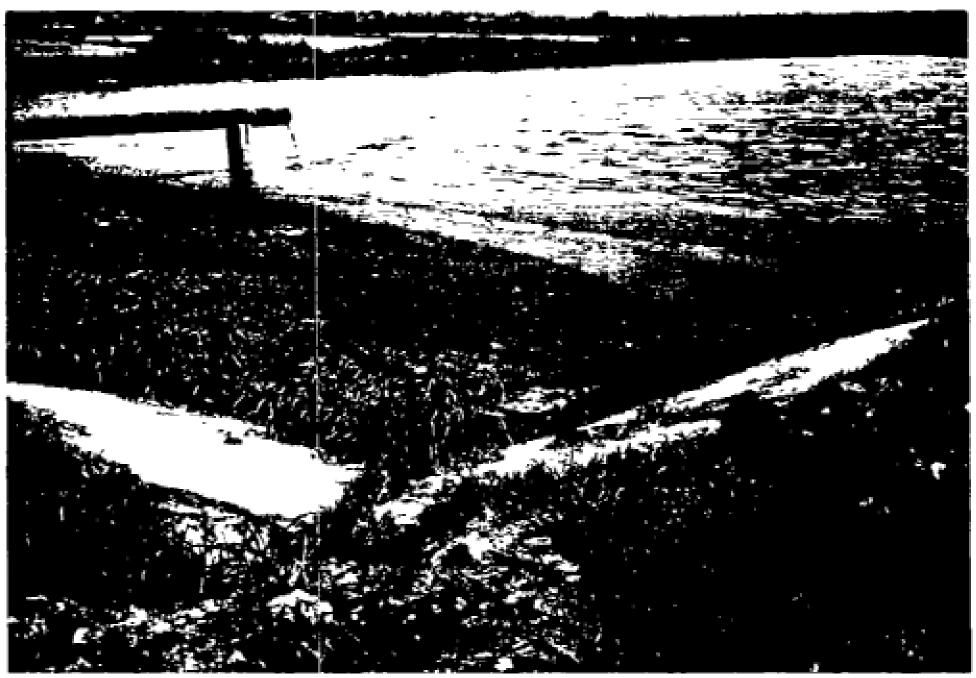


Figure 10. A view of the Vingunguti anaerobic ponds showing the inlet pipe and scum accumulation.

- The usual blue/green colour of the facultative pond wastewater disappeared in some days and no algae was seen. This may be brought about by the toxicants from the industries which were loaded in the ponds periodically. However, the normal condition of the facultative pond water was restored after three to four days.

- Some of the concrete channels making the outlets of the ponds have deteriorated thus water was leaking through the embankments (Figure 11).

Figure 11. One of the cracked concrete channels at Vingunguti waste stabilization ponds causing wastewater to by-pass the installed V-notch weir.

- A considerably large portion of the fence that marks the boundary of the pond site has been damaged and the nearby residents were always trespassing through.

- People have built houses adjacent to the pond site. This has made them victims of the nuisance from odour and mosquito breeding (Figure 12).

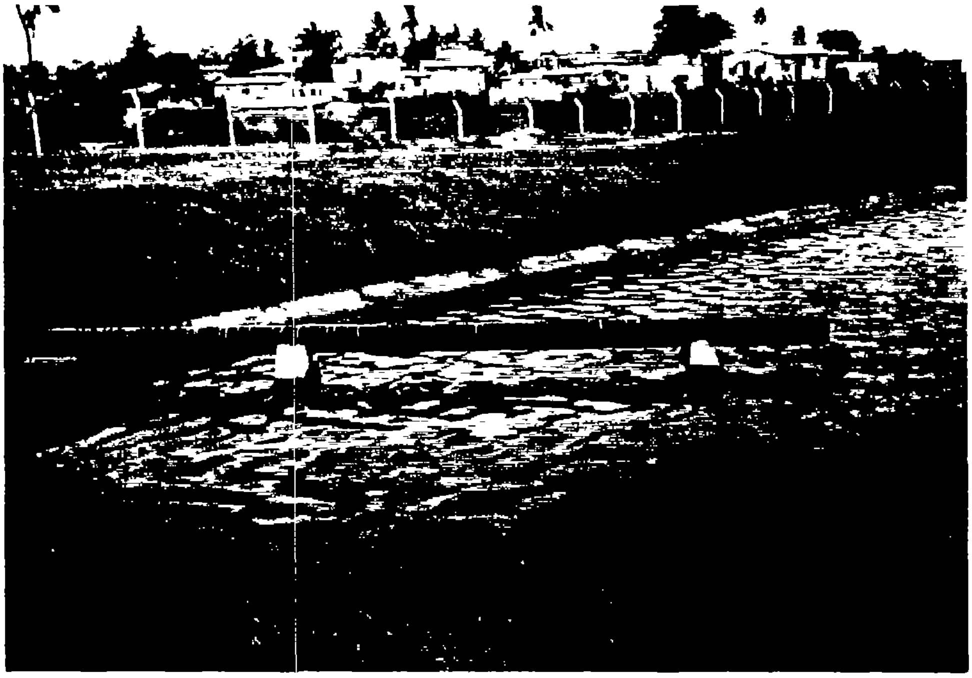


Figure 12. A view showing the inlet pipe into the Vingunguti facultative pond conveying industrial wastewater. Neighbouring residential houses are adjacent to the ponds.

- There were no flow measurement facilities at the inlets and outlets of the ponds. For regular monitoring of the ponds, flow measurement is essential.

- The final effluent from the ponds was used for watering nearby gardens before the rest was let to flow to the Msimbazi River. If the crops grown are consumed uncooked, a health hazard may occur.

- The raw industrial sewage was screened at the inlet to the facultative pond but there was no oil separation facility to remove grease and oil coming with the industrial wastewater (Figure 13).

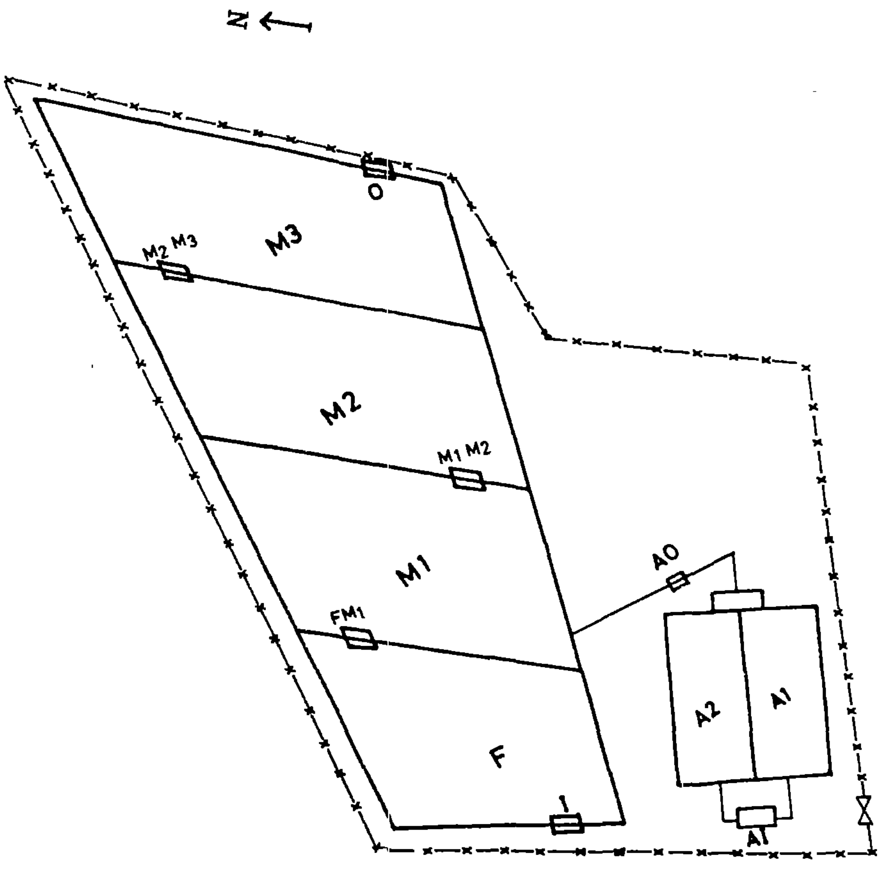
Figure 13. Screening facility at the inlet to the facultative pond at Vingunguti.

- The inlet pipes into anaerobic and facultative ponds were above the pond water level. This may be causing short-circuiting.

5 SAMPLING, ANALYSIS AND DISCUSSION OF RESULTS

5.1 Sampling and analysis

Samples were collected during eight weeks (November 1991 - January 1992) between 9.00 am and 12.00 noon. Seven samples were collected twice per week. Samples were taken from inlets and outlets of each pond unit to enable evaluation of the performance of each pond (Figure 14).



Legend

AI = inlet for anaerobic ponds (domestic wastewater inlet)
AO = outlet for anaerobic ponds
I = inlet for facultative pond (industrial wastewater inlet)
FM_1 = outlet for facultative pond
M_1M_2 = outlet for the first maturation pond
M_2M_3 = outlet for the second maturation pond
O = outlet for the last maturation pond

Figure 14. Sampling points at Vingunguti waste stabilization ponds.

Composite sampling is the recommended sampling technique whereby samples are collected at regular intervals and then mixed in one large sample over a period of 24 hours. Throughout this study, however, grab sampling has been used due to time limitation and inadequacy of sampling bottles and other necessary facilities. Pearson et al (1987) reported that for the determination of pH and fecal coliforms, grab samples are required.

Pearson et al (1987) also recommended two sampling periods for better evaluation of waste stabilization ponds; during the hottest and coldest seasons of the year. This was not possible since the field study period was limited to six months. Sampling for this study was done during the hottest period of the year (November - January). Therefore, the performance of the Vingunguti waste stabilization ponds can only be evaluated in this particular period and not in the extreme climate periods.

The parameters analysed in the laboratory were biological oxygen demant (BOD_5), total dissolved solids (TDS), fecal coliforms (FC), fecal streptococci (FS), pH, ammonia, nitrite, nitrate, copper and chromium. Samples were not collected from the industries for laboratory analysis. This was due to the big number of industries that were involved, the limitaion of time available and most important, the difficulty in testing heavy metals in the laboratory. Only a few samples from the Vingunguti waste stabilization ponds were tested for heavy metals during this study. Heavy metals and toxicants would have been parameters of first priority if wastewater samples from the individual industries were tested.

The analyses were carried out at the water section laboratory of the Faculty of Engineering at University of Dar es Salaam. The parameters analysed were selected after considering the importance in waste stabilization ponds, the capacity of the laboratory and the time available for the study. All the parameters were analyzed according to the standard methods for examination of water and wastewater.

Unfiltered samples were tested for BOD_5. Analyzes were done under standard conditions:the sample was stored for five days in the dark at 20 °C. In case analysis was not possible immediately after sampling, samples were stored for not more than 24 hours. Dissolved oxygen was measured, using dissolved oxygen meter, before and five days after storing the sample in the dark.

All samples for the bacteriological tests were collected in sterilized sampling bottles and tested immediately on arrival at the laboratory. The fecal coliform and the fecal streptococci bacteria were measured using the standard membrane filter procedure according to the standard methods.

Ammonia, nitrite, nitrate were measured using Lovibond raw water test kit and TDS was measured by a HACH TDS-meter. pH was determined by Orion pH-meter and heavy metals were tested using DR 200 Spectrophotometer. The on-site tests included determination of dissolved oxygen and temperature in the ponds using temperature/dissolved oxygen meter type YSI model 54A.

5.2 Results and discussion

In this chapter, presentation and discussion is made on the records obtained of the truck emptiers visiting the site daily and the information collected from the questionnaires sent to the various industries. The results of laboratory analyses and the results of the on-site analyses, including flow measurements, are also presented and discussed. Appendix 1 shows the detailed results of laboratory analyses and Appendix 2 Tanzanian temporary standards for effluents.

5.2.1 Report on truck emptiers and questionnaires

Truck emptiers

Table 12 shows the trips made weekly by the truck emptiers to Vingunguti waste stabilization ponds. Some difficulties were faced during interviews with the truck operators: in some cases it was not possible to obtain true information on which area of the city or what industry the wastewater has been collected from.

Table 12. Truck emptiers discharging wastewater into Vingunguti waste stabilization ponds (12.11.1991 - 11.1.1992).

Week	Total no. of trips per week	No. of trips residential areas	No. of trips from industrial areas	Name of industry
1	139	111	28	KIUTA and Rajani
2	143	126	17	KIUTA and Rajani
3	137	113	24	ALAF, KIUTA and Leyland Paints
4	81	76	5	Rajani
5	125	125	0	
6	140	136	4	Chandaria
7	71	71	0	
8	160	150	10	Chandaria

Average no. of trips per day = 26
Maximum " " " " " = 36
Minimum no. of trips per day = 14
Percentage of domestic wastewater brought by the emptiers = 91 %.

The industrial wastewater carried by truck emptiers is brought to the ponds periodically, that is once after a couple of days. This implies that the industries concerned drain their wastewater into pits or underground tanks where it is stored for some days before it is taken to the pond site.

The average number of trips per day is 26. More than 90 % of the wastewater brought to the pond site in truck emptiers is domestic. According to the interviewed truck operators, the domestic wastewater brought to the ponds was collected from different parts of Dar es Salaam city including areas beyond Temeke district. Howard Humphreys (1988) reported that the anaerobic ponds at Vingunguti were designed to treat domestic wastewater from Temeke district alone. This practice, which was a result of closure of some other pond systems in the city, may lead to suspect hydraulic overloading of the ponds.

Questionnaires

According to the questionnaires distributed to the various industries (Appendix 3) along Pugu Road, the information collected from the operators of truck emptiers and discussion with the authorities of the Dar es Salaam Sewerage and Sanitation Department (DSSD), 20 industries are reported to discharge their effluents into Vingunguti waste stabilization ponds (Table 13). However, the figure may be slightly lower than the actual because there are still some unknown industries that use truck emptiers to deliver illegally their wastewaters to Vingunguti pond site.

Table 13. Industrial wastewater sources and pollutants discharged into Vingunguti ponds.

Industry	Type of production/ activity	Major pollutants	Wastewater disposal
TASIA	production of vehicle springs	oil, domestic wastewater	sewer
Tropical Foods	fruit canning and bottling	high organic wastes, sugar and oil	sewer
Steelwool	production of steelwool	domestic wastewater	sewer
Paper Products	printing	colour, suspended solids	sewer
Diamond Motors	maintenance of vehicles and sales of spare parts	grease, oil and domestic sewage	sewer
Pattex Knitwear	production of textile material	colour, suspended solids	sewer
CALICO Textile Industry	production of textile material	colour, suspended solids	sewer
SADOLINS	production of paints	oils, colour	sewer
TAZARA workshop	maintenance of automobiles	oil, grease and domestic wastewater	sewer
TANITA	cashewnut processing	oil, suspended solids	sewer
YUASA battery	manufacturing batteries	acids, lead, zinc	sewer
ALAF	manufacturing corrugated iron sheets, asbestos sheets and galvanized pipes	toxic metals, heavy metals	truck
Galaxy Paints	production of paints	oils, colour	sewer
Leyland Paints	production of paints	alkalis, colour, oil	truck
Rajani Oil	production of cooking oil	oils	truck
KIUTA	paper binding/printing	colour, suspended solids	truck
Incar (T)	maintenance of vehicles and sales of spare parts	grease, oil	truck
Chandaria	manufacturing plastic bottles and toilet paper	suspended solids, domestic waste	truck
Tanzania Autoparts	pickling of steel sheets and sales	acids, oil, domestic wastewater	truck
National Distilleries	laboratory works	acids, suspended solids	truck

There are two categories of industries discharging effluents into Vingunguti ponds:

1 those disposing wastewater through a sewer system directly to Vingunguti ponds

2 those draining wastewater into pits located within the industrial premises. The wastewater is then collected by truck emptiers from the pits and transported to Vingunguti ponds.

The effluents from the industries have been categorized into three groups:

1 Effluents consisting of biodegradable organic material. Effluents from food processing industries and industries producing seed or vegetable oils fall under this category. These industries include Tropical Foods, TANITA and Rajani Oil. Other industries like Steel Wool (T) Limited and Chandaria do not use water in their processes. The wastewater generated by such industries is almost domestic, coming from canteens and toilets. This type of wastewater can easily be treated in waste stabilization ponds.

2 Effluents containing grease and oil. Industries dealing with maintenance of automobiles such as TAZARA workshop, Incar (T) Limited, Diamond Motors and TASIA produce this type of effluents. Grease and oil affect the performance of ponds, especially facultative and maturation ponds.

3 Toxic effluents containing substances like heavy metals (lead, zinc, copper, etc), acids and dyes. Industries producing this type of effluents include textile industries such as CALICO Textile Mill and Pattex Knitwear; printing industries like Paper Products and KIUTA; paints industries such as SADOLINS, Galaxy Paints and Leyland Paints; metal industries like Alaf and Tanzania Autoparts; and industries dealing with chemicals such as YUASA Battery and National Distilleries. Toxic substances inhibit the biological growth in ponds and hence their presence is a problem that cannot be overcome in the operation of pond systems.

5.2.2 Biochemical oxygen demand

Biochemical oxygen demand (BOD_5) measures the total amount of oxygen required to sustain biological activity in a pond. The BOD_5 reduction is generally the factor used for designing anaerobic and facultative ponds.

The values of BOD_5 at Vingunguti waste stabilization ponds during November 1991 - January 1992 are given in Table 14 and Appendix 4.

Table 14. BOD_5 values at Vingunguti waste stabilization ponds (November 1991 - January 1992).

Sample point	BOD5		
	mean mg/l	min mg/l	max mg/l
AI	186	160	210
AO	173	140	220
I	221	200	250
FM_1	135	100	160
M_1M_2	121	110	130
M_2M_3	123	110	140
O	107	80	140

According to Arthur (1983), raw domestic wastewater in African countries usually contains 350 mg BOD_5/l. This figure is different from the mean value of 186 mg BOD_5/l for the raw wastewater samples collected from the truck emptiers believed to carry more than 90 % domestic wastewater. Mogensen and Lunddal (1991), however, obtained a mean value of 109 mg BOD_5/l for the raw wastewater treated in Lugalo waste stabilization ponds. This value is even lower especially when it is considered that Lugalo ponds are receiving only domestic wastewater. Data from various waste stabilization ponds in Dar es Salaam show values of BOD_5 of raw domestic wastewaters ranging 120 - 220. Suki et al (1988) have reported average value of 137 mg/l and maximum value of 188 mg/l for BOD_5 of raw domestic wastewater from residential areas in Kuala Lumpur, Malaysia.

The BOD_5 effluent value of 107 mg/l was higher than that recommended by the Tanzania Temporary Standards (TTS) for effluents that are directly discharged into receiving water bodies (30 mg/l). There are different opinions on the subject of algae and their effect on BOD values. Varma et al (1963) cited by Mogensen and Lunddal (1991) noted that when algae die, being organic material, begin to decay and hence increase the BOD of the sample. The high concentration of algae observed in the maturation ponds might have similarly affected the effluent BOD_5 results obtained.

From Table 15, the BOD_5 removal percentages in ponds A, F, M_1, M_2 and M_3 were 7 %, 39 %, 20 %, -2 % and 13 % respectively. Total BOD_5 removal was 48 %. Anaerobic ponds are not expected to have BOD_5 removal efficiency below 60 % for design temperatures >20 °C (Mara and Monte 1990). According to Howard Humphreys (1988), the Vingunguti anaerobic ponds were designed for BOD_5 removal of 70 %. The strong smell coming out from the anaerobic ponds may also lead to suspect that the ponds are not performing well. Objectionable smell is normally caused by overloading of ponds and hence reducing the retention time or by the presence of toxic substances in the influent (WHO 1987). The retention time can as well be reduced when there is excessive accumulation of sludge causing the reduction of the pond volume. The poor performance of the anaerobic ponds may also be due to short-circuiting since the inlet pipes to the ponds were well above the surface water levels of the ponds. The raw wastewater may not be passing through all the expected purification processes in the ponds.

Table 15. Efficiency of each pond unit and total efficiency of Vingunguti waste stabilization ponds in the removal of various parameters during November 1991 - January 1992.

Parameter	Unit	A	F	M1	M2	M3	Total
BOD_5	%	7	39	20	-2	13	48
NH_3-N	%	-3	4	7	11	3	19
FC	%	4	93	62	57	77	99
FS	%	20	85	66	67	75	99
TDS	%	47	-7	17	0	-1	44
NO_3-N	%	7	17	-5	0	13	20
NO_2-N	%	17	47	23	-3	33	51
Cu	%	50	-	-	-	-	68
Cr	%	-68	-	-	-	-	-15

Note: 1. Mean concentrations were used in calculating the percentage removals. All values that deviated abnormally from other values were omitted (marked in brackets in Appendix 1).

2. The influent concentrations entering pond M_1 were calculated as the sum of the flow-weighted average concentrations coming from anaerobic and facultative ponds through points AO and FM_1 respectively.

Most of the samples taken directly from the truck emptiers contained some pesticides. Residents were said to be putting pesticides (such as DDT) in their pit latrines or septic tanks to eradicate the strong odour of the sewage in their premises and also to inhibit mosquito breeding. Pesticides are highly toxic already in very small concentrations.

Values for removal of BOD_5 for typical domestic sewage in facultative ponds is 70 - 90 % (Arceivala 1989). The efficiency of the facultative pond at Vingunguti in the removal of BOD_5 was 39 %. This low removal may be attributed to the fact that the facultative pond was receiving wastewater directly from industries. The presence of toxic substances accompanying industrial wastewater causes the die-off of microorganisms hence reducing the BOD removal efficiency of the facultative pond.

Maturation ponds are mainly designed for reducing pathogenic organisms, therefore their poor performance in the removal of BOD_5 can be accepted.

5.2.3 Fecal coliforms and fecal streptococci

Fecal coliform (FC) and fecal streptococci (FS) tests are both applied to indicate fecal contamination of water and wastewater (Feachem et al 1983). In this study, the tests were done to indicate the pathogenic bacteria removal in the pond system. Table 16 shows the calculated mean values of FC and FS counts which are also presented graphically in Figure 15.

Table 16. Mean, minimum and maximum values of FC and FS counts at Vingunguti waste stabilization ponds during November 1991 - January 1992.

Sample point	FC (counts/100 ml x 10^3)			FS (counts/100 ml x 10^3)		
	mean	min	max	mean	min	max
AI	600	240	1670	1548	370	6600
AO	575	85	1070	1232	210	3950
I	1232	120	1970	1840	910	3500
FM_1	87	4	301	280	32	1470
M_1M_2	115	8	366	243	18	1060
M_2M_3	49	3	102	80	21	181
O	12	2	38	20	5	39

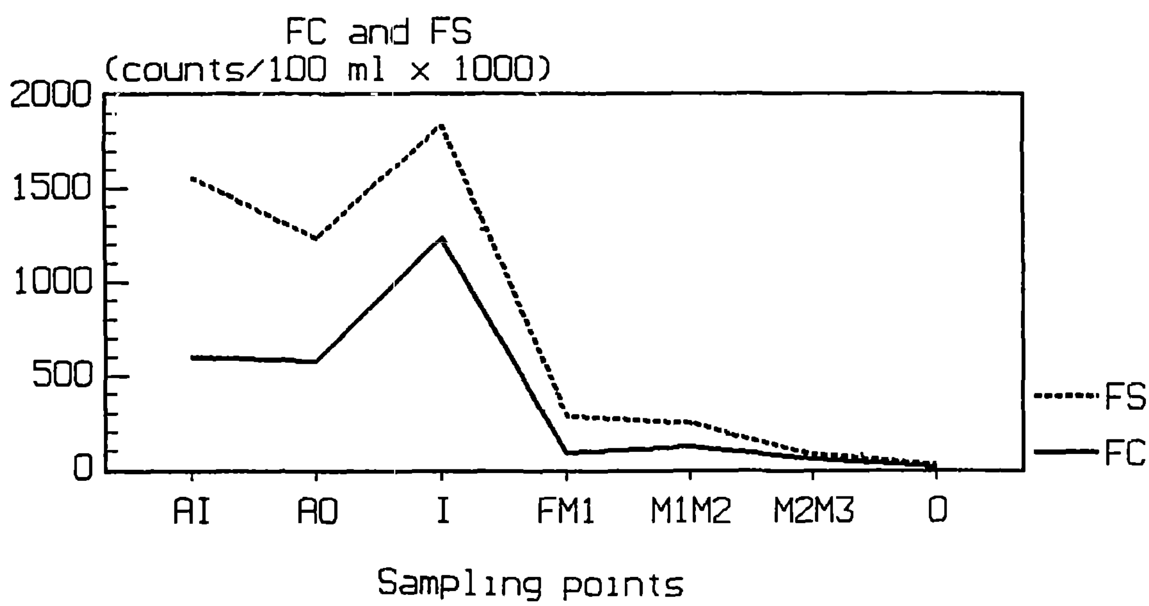


Figure 15. Mean values of FC and FS counts at Vingunguti waste stabilization ponds during November 1991 - January 1992.

The identical pattern of FC and FS reduction rate shown in Figure 15 by the two different curves indicates that the results can be relied on.

Mara (1977) cited by Mogensen and Lunddal (1991) suggested that for the purpose of designing stabilization ponds, a value of 1×10^8 counts/100 ml FC be used for raw domestic sewage. A value of 0.4×10^8 FC counts/100 ml was used for the design of Vingunguti ponds. Both these values are above the value of 0.006×10^8 counts/100 ml observed on the raw domestic wastewater discharged into the Vingunguti ponds.

The limit recommended by the TTS for effluents from ponds (5×10^3 counts/100 ml FC) has been surpassed. The final effluent contains 11.5×10^3 counts/100 ml FC. No mention has been made of the effluent standards for FS.

From table 15, the percentage removal of FC for ponds A, F, M_1, M_2, and M_3 were calculated as 4 %, 93 %, 62 %, 57 % and 77 % respectively. The ability of anaerobic ponds to remove FC is usually insignificant. Very high removal of FC and FS found in the facultative pond which have also been indicated by sharp decline of the two curves in Figure 15, may not be due to the normal operation of the pond itself. It may be attributed to the presence of toxic substances from industries which kill most of the microorganisms in the pond including the pathogenic bacteria.

Fecal coliform reduction in each maturation pond (ranging 57 - 77 %) averaged less than 90 % theoretical reduction calculated by Marais (1974). The lower rates of die-off of pathogens in the individual maturation ponds at Vingunguti may be due to the high concentration of BOD_5 in the ponds. Gameson and Saxon (1967) cited by Moeller and Calkins (1980) have reported that algae, as suspended solids, hinder the penetration of solar radiation, thus reduce the efficiency of ponds in destroying fecal coliforms. They noted that a filtered sample exposed to sunlight resulted in coliform destruction up to seven times that of unfiltered sample.

The individual performance of the maturation ponds at Vingunguti with fecal coliform reduction of 57 - 77 % was, however, similar to that of the West Hickman Creek wastewater lagoons in Kentucky, USA which showed mean reduction of fecal coliform ranging 62.9 - 77.4 % (Moeller and Calkins 1980).

During examining the bacteriological quality of the West Hickman Creek wastewater lagoons in Kentucky, USA., Moeller and Calkins (1980) noted that coliform densities in the final three maturation ponds exhibited a distinct parallelism throughout the sample period. That is an increase in coliform density from one sample date to the next in the first pond was usually accompanied by a rise in the second and third ponds. Similarly, a decrease in coliform concentration in the first pond was usually indicative of a decrease in the final ponds. A similar trend was observed on the facultative pond (F) and the two maturation ponds (M_1 and M_2) at Vingunguti (Figure 16). The concentrations of fecal coliforms in the effluents from the last maturation pond M_3 were too small to be plotted on the graph.

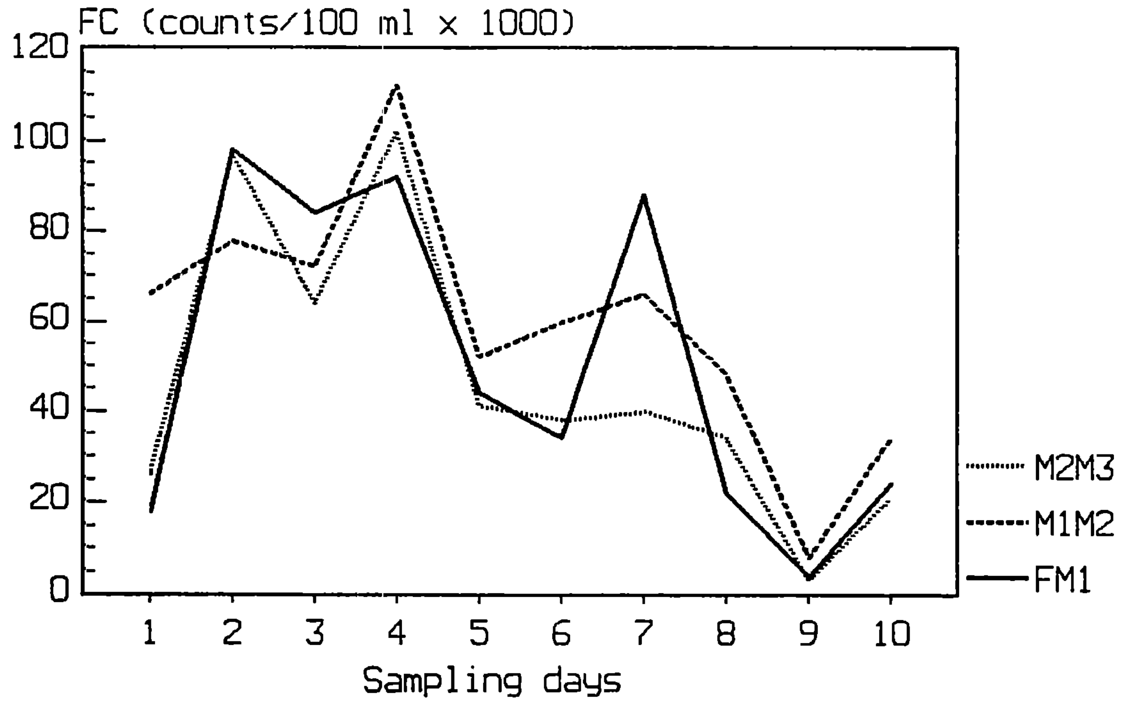


Figure 16. Fecal coliform densities in the facultative pond (F) and maturation ponds (M_1 and M_2) during November 1991 - January 1992.

5.2.4 Total dissolved solids

Table 17 shows the TDS values measured at Vingunguti waste stabilization ponds during the study. The graphical presentation of the values is given in Appendix 4.

Table 17. Mean, minimum and maximum values of TDS at Vingunguti ponds during November 1991 - January 1992.

Sample points	TDS		
	mean mg/l	min mg/l	max mg/l
AI	1202	347	6390
AO	642	320	1150
I	320	220	436
FM_1	343	260	460
M_1M_2	397	350	480
M_2M_3	397	347	480
O	400	330	483

The effluent standard for TDS is 3 000 mg/l. The measured effluent TDS value of 400 mg/l indicates that the performance of Vingunguti ponds has met the effluent requirements recommended by the TTS. Table 15 shows that the anaerobic ponds have removed TDS contents by 47 %. According to this study, anaerobic ponds were the only pond units where TDS were removed significantly. This may be due to the sedimentation process that takes place in the anaerobic ponds. In the facultative and last maturation ponds, TDS contents have shown to increase slightly (1 - 7 % increase). This might be a result of the suspended algae that grow in the facultative and maturation ponds. The shallow depth of the maturation ponds may also cause the detection of high TDS values due to easy mixing of the settled particles by wind action.

5.2.5 Ammonia, nitrate and nitrite

Ammonia (NH_3-N)

The ammonia concentrations are given in Table 18 and Appendix 4. The effluent requirement for ammonia recommended by TTS is 10 mg/l N. The Vingunguti pond system has shown to meet this requirement as the effluent ammonia content was 7.0 mg/l N.

Table 18. Mean, minimum and maximum concentrations of ammonia at Vingunguti waste stabilization ponds during November 1991 - January 1992.

Sample point	NH_3-N		
	mean mg/l	min mg/l	max mg/l
AI	9.8	7.0	17.8
AO	10.1	5.0	20.0
I	8.0	3.9	13.4
FM_1	7.7	1.2	12.6
M_1M_2	8.2	0.5	12.0
M_2M_3	7.3	0.3	14.0
O	7.1	0.5	12.6

The quality of the effluents from Vingunguti ponds with respect to nitrate and nitrite concentrations was relatively better than of many operating ponds. Batchelor et al (1991) reported typical effluent concentrations of nitrate and nitrite from waste stabilization ponds as 15.7 mg NO_3-N/l and 0.3 mg NO_2-N/l respectively. The effluent concentrations of nitrate and nitrite from Vingunguti waste stabilization ponds were 7.3 mg NO_3-N/l and 0.4 mg NO_2-N/l respectively. This may be due to low influent concentrations of the nitrogen compounds experienced by the ponds.

Table 15 shows that the percentage removal of ammonia in ponds A, F, M_1, M_2 and M_3 were -3 %, 4 %, 7 %, 11 % and 3 % respectively. The total reduction of ammonia through the Vingunguti pond system was 19 %. This total removal efficiency is lower than anticipated. Removal efficiencies of ammonia in waste stabilization ponds have been reported up to 99 % during summer with a minimum value of 90 % during winter in California (USEPA 1983).

The removal of ammonia in ponds is carried out through the nitrification processes. These processes, like all other biological processes, are sensitive to the presence of toxic compounds including some heavy metals found in industrial wastewaters. The ammonia removal efficiency of the Vingunguti ponds may have been affected by the presence of chromium in the wastewater. Beg et al (1980) found out that under shock load condition, chromium has a significant degree of inhibition to nitrification process (even higher than arsenic or fluoride), thus affecting the removal efficiency of ammonia in a biological treatment plant. However, the effect of the same toxicant over a long period of time may not be the same as under shock load conditions.

5.2.6 Heavy metals

The heavy metals tested were nickel, lead, cadmium, copper and chromium. Tests for cadmium, nickel and lead were stopped after performing for two days and find no traces of the metals. Copper and chromium were tested for nine days during the study. The reliability of the results of the heavy metal tests (Appendix 1) is, therefore, low.

Heavy metals like nickel, lead and cadmium are usually produced by such industries like metal industry and battery industry. Their concentrations at the Vingunguti waste stabilization ponds may have been too low to be detected by the available equipments.

5.2.7 Dissolved oxygen, temperature and pH

Due to lack of proper equipment for measuring dissolved oxygen (DO) levels and water temperatures (T) along the pond depth, as recommended by Pearson et al (1987), these parameters were measured on the upper water levels only. The measurements were, however, taken after sampling period was over as the dissolved oxygen meter for field measurements was not available at the beginning. The results (Table 19), therefore, cannot be directly correlated with the laboratory analyzes results obtained earlier.

Table 19. Dissolved oxygen (DO) and temperature (T) measurements at Vingunguti waste stabilization ponds (10. - 14.2.1992).

Date	Dissolved oxygen and temperature									
	AO		I		FM_1		M_1M_2		M_2M_3	
	DO mg/l	T °C	DO mg/l	T °C	DO mg/l	T °C	DO mg/l	T °C	DO mg/l	T °C
10.2.1992	7.8	24.0	6.0	22.5	11.8	23.0	10.6	23.5	11.0	22.0
11.2.1992	4.8	22.0	5.8	22.5	8.8	22.0	6.6	22.0	10.0	22.0
12.2.1992	5.2	21.5	4.4	22.5	12.4	21.5	7.6	21.0	7.8	21.0
13.2.1992	3.6	21.5	2.2	22.0	9.4	21.5	6.0	22.0	7.5	21.0
14.2.1992	6.4	21.5	4.8	22.0	12.0	22.0	7.2	22.0	7.8	21.0
Average	5.6	22.1	4.6	22.3	12.0	22.0	7.6	22.1	8.8	21.4

The raw industrial wastewater that enters into the facultative pond had the lowest average DO content (4.6 mg/l). The most interesting observation was that the facultative pond effluents, however, possessed the highest average DO content in the pond system (12.0 mg/l). This may be mainly due to the algal photosynthetic processes taking place in the facultative pond which caused the DO content of the industrial wastewater to raise tremendously.

Effluents from the first maturation pond had lower average DO content (7.6 mg/l) than that of the effluents from the facultative pond (12.0 mg/l). This was because, in addition to the facultative pond effluents, the first maturation pond receives also anaerobic pond effluents which had lower average DO content (5.6 mg/l). With the exception of the values at the outlet of the facultative pond, the remaining values of DO content generally indicate the anticipated trend of increasing DO content as the purification process proceeds. The higher values of DO downstream are due to oxygen added through algal photosynthetic activity. This is also signified by the increase in pH downstream (Oswald 1991).

It was not possible to measure the DO content of the final effluents from the pond system for the whole week. Due to some rains that were falling during this period, there was a mixture of pond water and stream water at the outlet of the last maturation pond and the readings obtained were not logical.

The average pond water temperature (at the surface) was 21.9 °C. The raw industrial wastewater showed to have slightly higher average temperature (22.3 °C).

pH measurement was done in the laboratory. Average pH values at Vingunguti waste stabilization ponds ranged 7.3 - 8.3 (Appendices 1 and 4), the higher values being at the downstream of the pond system. Zimba (1986) has reported pH values ranging between 6 - 9 for selected pond systems in Zambia, the effluent pH values being similarly higher than the influent values. The higher average value of pH recorded at Vingunguti ponds (8.3) was below the required for optimum destruction of pathogens. Oswald (1991) reported that a pH of 9.2 for 24 hours will provide a 100 % kill of E. Coli and presumably most pathogenic bacteria.

5.2.8 Flow measurement

Measurement of flow were done using 90° V-notch weirs made of steel (Figure 17).

Figure 17. A 90° V-notch weir installed at Vingunguti waste stabilization ponds.

Calibration of the weirs was done at site: a bucket of 11.5 l was filled with pond effluent at the downstream side of each weir. The time to fill the bucket at every weir was recorded five times. Corresponding water head measurements (h) at the V-notches were also recorded. Actual discharges through the weirs were calculated from the volume of the bucket and the time durations recorded.

Theoretical discharges were determined from the water head measurements (h) using the formula (Lindford 1981):

$$Q = \frac{8}{15} (2 \cdot g)^{\frac{1}{2}} \tan (v/2) \cdot h^{5/2} \qquad (25)$$

where Q = theoretical discharge (m^3/s)
h = water depth over the V-notch (m)
g = gravitational acceleration (9.81 m/s2)
v = V-notch angle (90°).

The coefficient of discharge (Cd) was determined as:

$$Cd = \frac{\text{actual discharge}}{\text{theoreticatl discharge}}$$

The resulting average coefficient of discharge for all the weirs was 0.5.

Discharges through the V-notches were, therefore, calculated from the observed water heads (h) using equation (25) multiplied by this factor (0.5).

The weirs were installed at points AO, FM_1, $M_1 2$, M_2M_3 and O. Influent flow into anaerobic ponds was estimated from the average number of truck emptiers that reported at the pond site daily. The capacity of one truck emptier was 7 000 l. Industrial wastewater inflow into the facultative pond was estimated using a current-meter for one day.

Leakage around the edges of the V-notches was well prevented using strong cement mortar but it was not possible to seal the cracks in some channel walls which let the wastewater by-pass the V-notches especially at point M_1M_2. Water head readings at the V-notch weirs were taken between 9.00 am and 4.30 pm, three times daily (Table 20).

Table 20. Discharge measurements at Vingunguti waste stabilization ponds (10. - 14.2.1992).

Date	Time	Discharge			
		AO l/s	FM_1 l/s	M_1M_2 l/s	M_2M_3 l/s
10.2.1992	9.30 am	1.18	4.22	5.89	5.30
	1.00 pm	2.34	4.22	5.30	4.96
	3.30 pm	2.00	3.74	4.74	4.22
11.2.1992	9.40 am	4.02	2.56	3.74	3.37
	1.40 pm	3.12	1.94	3.29	2.87
	3.30 pm	2.71	1.82	2.42	2.14
12.2.1992	9.30 am	0.96	2.14	3.74	3.74
	11.15 am	1.18	2.34	2.87	2.71
	2.30 pm	1.09	1.53	1.82	1.70
13.2.1992	9.40 am	1.00	1.76	2.14	1.94
	00.30 pm	0.73	1.42	1.42	1.37
	3.44 pm	1.27	1.27	1.27	1.22
14.2.1992	9.57 am	1.18	1.82	2.49	2.14
	2.10 pm	2.42	1.53	2.64	2.56
	4.20 pm	2.34	1.53	2.56	2.42
Average		1.84	2.26	3.09	2.72
Minimum		0.33	1.27	1.27	1.22
Maximum		4.02	4.22	5.89	5.30

It was not possible to take readings at the outlet of the last maturation pond (point O). The weir installed at this point was damaged by a collapsing wall of the outlet channel. As the wall was leaning against the weir, the weir got deformed and it was unsafe to work near the place.

Table 20 shows that the inlet flow was always greater than the outlet flow for each pond unit. This loss was due to leakage through cracks on the channel walls, seepage through the bottom of the ponds and evaporation. The percentage difference between inflow and outflow for ponds A, M_1 and M_2 were 13 %, 24 % and 12 % respectively. A relatively larger fraction of effluent from pond M_1 (24 %) was not passing through the installed V-notch weir. This was due to the large cracks found at the outlet channel of this pond causing the pond effluent to by-pass the weir. The average loss of wastewater in each pond due to evaporation and seepage can be estimated from the anaerobic ponds and the second maturation pond to be 12.5 %.

It is most likely that evaporation and seepage have taken a significant volume of the pond waters causing inflow to be greater than outflow. This is because the study period coincided with the hottest and dryest season of the year (November - January) and also because the pond bottom was unlined. Table 21 shows the montly temperature and rainfall recorded at the University of Dar es Salaam meteorological station during the sampling period.

Table 21. Monthly temperature and rainfall during November 1991, December 1991 and January 1992 (University of Dar es Salaam meteorological station 1992).

Month	Air temperature			Average rainfall
	max °C	min °C	mean °C	mm
November 1991	31.5	11.6	21.6	5.3
December 1991	30.8	12.0	21.4	4.2
January 1992	30.7	13.3	22.0	0.6

The measured flows (Table 20) were smaller than the design flows. This may be because the design flows were projected 20 years ahead (from 1988). Therefore the ponds are now working under capacity (hydraulically).

5.2.9 Applicability of design equations

<u>Anaerobic pond design equations</u>

The actual surface loading into the Vingunguti anaerobic ponds based on the actual values of influent BOD_5 and average inflow rate, was 850 kg/ha·d. Anaerobic ponds are required to have surface loadings more than 1 000 kg/ha·d. This shows that the provided surface area of the ponds was slightly (about 1.2 times) larger than required. However, surface loading is not recommended for use in sizing anaerobic ponds (Gloyna 1971 cited by WHO 1987).

The volumetric loading into the Vingunguti anaerobic ponds calculated with equation (10) based on the actual values of influent BOD_5 and inflow rates was 28 $g/m^3 \cdot d$. The design volumetric loading for temperatures >20 °C is 300 $g/m^3 \cdot d$ (Mara and Monte 1990). This indicates that the volume of the anaerobic ponds is about 10 times greater than required using the volumetric loading rate design method.

The Vingunguti anaerobic ponds were designed with the retention time method (equation 11). The design flow was 240 m^3/d and the retention time was selected as 5 days resulting in a total volume of 1200 m^3. With the actual average flow of 182 m^3/d, the corresponding retention time during the study was 6.6 days indicating that the ponds were operating fairly below their capacity. However, according to Mara (1976 cited by WHO 1987), BOD_5 reduction should have been >70 % for retention times >5 days. The BOD_5 reduction at the Vingunguti anaerobic ponds was only 7 %.

Facultative pond design equations

Applying the Marais and Shaw first order reaction equation (18) with the actual values of influent and effluent BOD_5 and retention time, the resulting breakdown rate constant (k_T) was 0.0114 d^{-1}. The value of k_T calculated with equation (19) and taking the average temperature as 21.9 °C was 0.33 d^{-1}. The lower k_T value reflects the lower rate of removal of organic material in the facultative pond.

The bacterial die-off constant (k_b)

Table 22 gives the actual values of k_b calculated from the kinetic equation (22) based on the actual retention times of the pond units and actual average influent and effluent fecal coliform counts at Vingunguti ponds.

Table 22. Actual values of k_b at Vingunguti waste stabilization ponds (11.11.1991 - 9.1.1992).

Pond unit	Retention time d	kb d^{-1}
A	6.6	0.007
F	56.2	0.234
M_1	37.7	0.044
M_2	56.8	0.024
M_3	60.3	0.054

The k_b values for the three maturation ponds were not exactly equal, but were closer to be constant than those for the facultative and anaerobic ponds. The rate of fecal coliform die-off in the maturation ponds, therefore, closely obeyed the kinetic theory. The highest rate of fecal coliform die-off in the facultative pond has been reflected by the highest value of k_b in the pond system. In the normal checking of pathogenic bacteria removal in waste stabilization ponds using equation (23), k_b is taken as constant for all types of ponds (anaerobic, facultative and maturation). This may not be correct as demonstrated by the variation of k_b values on Table 22. The reduction mechanisms in the three types of ponds are different.

Applying equation (24) and taking the pond water temperature as 21.9 °C, the value of k_b is 2.96 d^{-1}. This value is far different from the values calculated in Table 22.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The quality of effluents from the Vingunguti waste stabilization ponds do not comply with the requirements of the Tanzania temporary standards. This is concluded from the higher concentrations (than the standards) of the most important parameters - BOD_5 and FC - observed in the final effluents from the ponds. Effluent BOD_5 and FC were 107 mg/l and 11 500 counts/100 ml respectively whereas the standard requires 30 mg/l BOD_5 and 5 000 FC counts/100 ml.

The concentrations of NH_3-N, NO_3-N, NO_2-N and TDS (7.1 mg/l, 7.3 mg/l, 0.4 mg/l and 300 mg/l respectively) have met the effluent standard requirements, but this may be mainly because the concentrations of the parameters in the raw wastewater received by the ponds were already low.

With the exception of pathogenic bacteria removal, the overall treatment efficiency of the Vingunguti waste stabilization pond system was poor. Overall efficiencies in the removal of BOD_5, TDS and nitrogen compounds ranged 19 - 51 %. FC and FS removal was above 98 %.

The individual performance of the anaerobic ponds was the worst with a BOD_5 removal efficiency of 7 % only. The anticipated BOD_5 removal efficiency of an anaerobic pond is above 60 %. Ammonia was increasing by 3 % in the pond and nitrate and nitrite were removed by only 7 % and 17 % respectively. The anaerobic ponds have only been slightly effective in TDS removal (44 %) which, however, may be attributed to the sedimentation process in the pond and not the biological activities of the microorganisms.

The cause of the total failure of the anaerobic ponds at Vingunguti was not investigated in this study. It may be due to sludge accumulation, short-circuiting, presence of pesticides from pit latrines and septic tanks or toxicants from industries that discharge wastewater illegally using truck emptiers.

The performance of the facultative pond was better than the anaerobic ponds especially considering that the facultative pond was treating purely industrial effluents. BOD_5 was removed by 39 % and FC and FS by 93 % and 85 % respectively. The high die-off rate of pathogenic bacteria in the facultative pond is likely to be boosted by the toxicants from the industrial wastewaters. The industrial toxicants may, in contrast, be adversely affecting the removal of BOD_5 and the nitrogen compounds.

The three maturation ponds showed almost equal individual performances in pathogenic bacteria removal with the last pond (M_3) being slightly the best. Their removal efficiencies ranging 57 - 77 % are common in most well operating maturation ponds.

Investigations on effluents from individual industries could not be covered in this study. The few laboratory tests for copper and chromium done on samples collected from the facultative pond inlet at Vingunguti showed that these metals were present. Copper and chromium may be produced by metal processing or battery manufacturing industries. More heavy metals and other toxic substances from the textile, printing, paints and chemical industries along Pugu road are likely to be present in the Vingunguti ponds.

In this study, it has also been observed that the BOD_5 of raw domestic wastewaters from pit latrines, septic tanks and even conventional sewerage systems in Dar es Salaam may be on the range 120 - 220 mg/l. The value of 350 mg/l BOD_5 for raw domestic wastewater recommended by many authors for design of waste stabilization ponds in tropical areas may be too high for the Dar es Salaam region. However, for designing ponds to treat combined wastewater, this value (350 mg/l) may be too low, since effluents of some industries contain high BOD_5.

The DO contents and pH values at the Vingunguti waste stabilization ponds were rising downstream indicating that the ponds were operating normally. The average pH values in the maturation ponds (ranging 7.7 - 8.3), which were below 9.0, proved that the optimum destruction of pathogenic bacteria was not achieved.

6.2 Recommendations

Based on the findings of the study on the Vingunguti waste stabilization ponds the following is recommended:

1) Thorough investigation on the complete failure of the Vingunguti anaerobic ponds, in particular, should be carried out. Investigation on the poor overall performance of the Vingunguti pond system is also important. This should begin by focusing on the quality and quantity of wastewater discharged by each concerned industry.

2) A possibility to rearrange the wastewater flow at the Vingunguti waste stabilization ponds to follow the normal order should be studied. That is, all the raw wastewater (domestic and industrial) should enter the pond system through the anaerobic ponds. From the anaerobic ponds, the wastewater should flow into the facultative pond and finally into maturation ponds. Anaerobic ponds are important in pretreating various types of industrial wastewaters.

3) The concerned industries should be encouraged to pretreat their wastewaters to minimize the effects of the compounds inhibitory to microbiological activities in the ponds.

4) The crown levels of the raw wastewater inlet pipes entering the anaerobic and facultative ponds at Vingunguti are required to be at a sufficient depth

below pond water levels. This will enable easy mixing of the raw wastewater with the pond contents and hence avoid short-circuiting.

5) Simple and efficient means of removing algae from the final pond effluents is required to avoid secondary pollution to the Msimbazi river.

6) Maintenance and repair of the pond embankments and channel walls should be done whenever required to prevent further damage.

7) Flow, pH and temperature measurements at the Vingunguti ponds should be recorded daily. Regular analysis of important parameters, with emphasis on those found in industrial wastewaters, should be done for better monitoring of the ponds performance. This will help to make appropriate modifications to optimize the performance of the pond system.

8) Almost all the existing formulas for design of waste stabilization ponds are principally based on the removal of BOD and FC which are the common pollutants found in domestic wastewaters. This is because, originally, waste stabilization ponds were meant for domestic wastewater treatment. More studies should, therefore, be done on the effects of the various parameters found in different industrial wastewaters on the operation of waste stabilization ponds. This will facilitate establishment of more proper methods and formulas for designing waste stabilization ponds receiving combined industrial and municipal wastewaters.

7 REFERENCES

Alabaster, G.P., Mills, S.W., Osebe, S.A., Thitai, W.N., Pearson, H.W., Mara, D.D. and Muiruri, P. 1991. Combined treatment of domestic and industrial wastewater in waste stabilization pond systems in Kenya. Water Science and Technology. Vol. 24, no. 1, p. 43-52.

Al-Salem, S.S. and Lumbers, J.P. 1987. An initial evaluation of Alsumra waste stabilization ponds (Jordan). Water Science and Technology. Vol. 19, no. 12, p. 33-37.

Arceivala, S.J. 1986. Wastewater treatment for pollution control. McGraw-Hill Publishing Company Ltd. p. 115-143.

Arellano, F. 1987. Pollution problems and control measures for the metal plating, alcohol, industrial chemicals and paint manufacturing industries. Proceedings of the national training course on industrial pollution control for small and medium scale industries, November 22-27, 1987, Tagaytay, Philippines. p. 48-49.

Arthur, J.P. 1983. Notes on the design and operation of waste stabilization ponds in warm climates of developing countries. World Bank Technical Paper no. 7. The World Bank, Washington DC, USA. p. 7-61.

Banerji, S.K. and Ruess, B. 1987. Evaluation of waste stabilization pond performance in Missouri and Kansas, USA. Water Science and Technology. Vol. 19, no. 12, p. 39-46.

Batchelor, A., Bocarro, R. and Pylous, P.J. 1991. Low-cost and low-energy wastewater treatment systems: A South African perspective. Water Science and Technology. Vol. 24, no. 5, p. 241-246.

Beg, S.A., Siddiqi, R.H. and Ilias, S. 1980. Inhibition of nitrification by arsenic, chromium and flouride. Journal Water Pollution Control Federation. Vol. 54, no. 5, p. 482-488.

Bramer, H.C. 1976. Water pollution control in the metal industry. Industrial wastewater management handbook. McGraw-Hill Book Company, New York. p. (9-1)-(9-55).

Diaz, A. 1987. Pollution problems and control measures for the food industry. Proceedings of the national training course on industrial pollution control for small and medium scale industries, November 22-27, Tagaytay, Philippines. p. 34-37.

Egbuniwe, N. 1982. Performance of a waste stabilization pond treatment plant on a University campus. African Journal of Science and Technology. Vol. 1, no. 1, p. 32-40.

Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. 1983. Sanitation and disease: health aspects of excreta and wastewater management. World Bank Studies in Water Supply and Sanitation. John Wiley & Sons. 501 p.

Gathuo, B. 1984. Industrial wastewater discharges with special reference to leather industry in Kenya. M.Sc. Thesis. Tampere University of Technology, Finland. p. 25-26.

Germirli, F., Tünay, O. and Orhon, D. 1990. An overview of the textile industry in Turkey - pollution profiles and treatability characteristics. Water Science and Technology. Vol. 22, no. 9, p. 265-274.

Gilde, L.C. and Aly, O.M. 1976. Water pollution control in the food industry. Industrial wastewater management handbook. McGraw-Hill Book Company, New York. p. (5-1)-(5-51).

Grau, P. 1991. Textile industry wastewater treatment. Water Science and Technology. Vol. 24, no. 1, p. 97-103.

Greenberg, A.E., Trussell, R.R., Clesceri, L.S. and Franson, M.A. 1985. Standard methods for the examination of water and wastewater. 16. edition. American Public Health Association (APHA), Washington, USA. p. 373-917.

Henry, J.G. and Gehr, R. 1980. Odor control: an operator's guide. Journal Water Pollution Control Federation. Vol. 52, no. 10. p. 2523-2537.

Henze, M. 1983. Industrial wastewater treatment in developing countries. The Danish Academy of Technical Sciences, Lyngby, Denmark. p. 20-27.

Holding, J. 1990. Effluent treatment: the options. World Water. Vol. 13, no.6, p. 16-17.

Horan, N.J. 1990. Biological wastewater treatment systems. Theory and operation. John Wiley and Sons, Chichester, England. p. 267-291.

Howard Humphreys (Tanzania) Ltd. 1988. Dar es Salaam sewerage and sanitation study - preliminary engineering design and feasibility study. Final report. 508 p.

Karpe, H.J. and Baumann, W. 1980. Wastewater treatment and excreta disposal in developing countries. Report on a research project by the Institute of Environmental Protection (INFU), University of Dortmund, Federal Republic of Germany. 121 p.

Linford, A. 1981. Flow measurement & meters. 5. edition.
Longhurst, S. and Turner, E. 1987. Combined treatment of industrial effluents. Industry and Environment, Vol. 10, no. 2, p. 11-16.

Lumbers, J. and Andoh, B. 1985. Waste stabilization pond design: Some myths behind the science. Waterlines. Vol. 3, no. 4, p. 12-14.

Mara, D.D. and Monte, M.H.F. 1990. The design and operation of waste stabilization ponds in tourist areas of Mediterranean Europe. Water Science and Technology. Vol. 22, no. 3/4, p. 73-76.

Mara, D. and Pearson, H. 1987. Designing against pond horrors. p. 17-21.

Marais, G.V.R. 1974. Fecal bacterial kinetics in stabilization ponds. Journal of the Environmental engineering Division, no. 2, p. 119-139

Mashauri, D.A. Mkuula, S.S., Mpendazoe, F.M. and Gumbo, F. 1990. Programme on purification of industrial wastewater. Country paper: United Republic of Tanzania. In: UNIDO regional meeting on management of industrial wastewater, December 10-14, 1990, Paris, France. p. 2-10.

Mayo, A. 1988. Bacterial die-off in waste stabilization ponds receiving domestic wastewater in Dar es Salaam, Tanzania. M.Sc. Thesis. Tampere University of Technology, Finland. 60 p.

Mayo, A.W. and Gondwe, E.S. 1989. Quality changes in ponds with different pond depth and hydraulic detention times. Water Quality Bulletin. Vol. 14, no. 3, p. 155-168.

Moeller, J.R. and Calkins, J. 1980. Bactericidal agents in wastewater lagoons and lagoon design. Journal Water Pollution Control Federation. Vol. 52, no. 10, p. 2442-2451.

Mogensen, U. and Lunddal, M. 1991. Evaluation of Lugalo waste stabilization ponds, Dar es Salaam, Tanzania. Diploma Project. Engineering Academy of Denmark. 91 p.

Munene, R.F.K. 1984. Performance of selected waste stabilization ponds in Kenya. M.Sc. Thesis. Tampere University of Technology, Finland. 111 p.

Novaes, R.F.V. 1986. Microbiology of anaerobic digestion. Water Science and Technology. Vol. 18, no. 12, p. 1-14.

Oswald, W.J. 1991. Introduction to advanced integrated wastewater ponding systems. Water Science and Technology. Vol. 24, no. 5, p. 1-7.

Parsons, W.A. 1976. Water pollution control in the chemical industry. Industrial wastewater management handbook. McGraw-Hill Book Company, New York. p. (5-1)-(7-1).

Pearson, H.W., Mara, D.D. and Bartone, G.R. 1987. Guidelines for the minimum evaluation of the performance of full scale waste stabilization pond systems. Water Research, vol. 21, no. 9, p. 1067-1074.

Pujol, R. and Lienard, A. 1990. Qualitative and quantitative characterization of wastewater for small communities. Water Science and Technology. Vol. 22, no. 3/4, p. 253-260.

Rantala, P. 1987. Problems with textile wastewater discharge. Seminar on wastewater treatment in urban areas, September 7-9, Visby, Sweden. p. 1-7.

Suki, A., Jenny, H. and Rashid, H. 1988. Efficiency of oxidation ponds. The proceedings of the 14th WEDC (Water Engineering and Development Centre) conference on water and urban services in Asia and the Pacific, April 11-15, 1988, Kuala Lumpur, Malaysia. p. 42-45

University of Dar es Salaam meteorological station. 1992. Records on daily meteorological measurements.

Upstone, M.P. 1990. Water pollution control and trade effluent policies in urban areas. In: 4th African Water Technology Conference, February, 20-22, 1990, Nairobi, Kenya. p. 108-111.

USEPA (United States Environmental Protection Agency). 1983. Design manual - municipal wastewater stabilization ponds, Cincinnati, USA. 327 p.

Vigneswaran, S., Balasuriya, B.L.N. and Viraraghavan, T. 1986. Anaerobic wastewater treatment - attached growth and sludge blanket process. Environmental Sanitation Reviews, no. 19/20. Environmental Sanitation Information Centre, Bangkok, Thailand. p. 1-5.

Wang, B. 1991. Ecological waste treatment and utilization systems on low-cost, energy saving/generating and resource recoverable technology for water pollution control in China. Water Science and Technology. Vol. 24, no. 5, p. 9-19.

WHO (World Health Organization). 1987. Wastewater stabilization ponds. Principals of planning and practice. WHO EMRO Technical publication no. 10. WHO, Regional Office For The Eastern Mediterranean, Alexandria, Egypt. 138 p.

Yayehyirad, G. 1984. Combined treatment of domestic and industrial wastewaters. M.Sc. Thesis. Tampere University of Technology, Finland. p. 21-51.

Zimba, R. 1986. Performance evaluation of selected waste stabilization ponds in Zambia. MSc thesis. Tampere University of Technology, Finland. 113 p.

Appendix 1 (1/5)

Biochemical oxygen demand (BOD_5) at Vingunguti waste stabilization ponds (26.11.1991 - 16.1.1992).

Date	Sampling points						
	AI	AO	I	FM_1	M_1M_2	M_2M_3	O
26.11.1991	190	150	220	100	120	110	100
28.11.1991	160	(230)*)	(140)	140	120	(160)	140
5.12.1991	(100)	140	250	100	120	(190)	(180)
10.12.1991	180	150	230	150	120	130	110
17.12.1991	190	210	200	130	120	120	130
19.12.1991	210	180	230	150	130	120	90
26.12.1991	190	220	220	150	130	130	110
31.12.1991	190	190	200	160	130	140	100
2.1.1992	(80)	160	(10)	(60)	(20)	(20)	(40)
7.1.1992	(70)	140	(150)	110	120	110	80
9.1.1992	180	200	240	140	120	130	100
14.1.1992	200	190	210	130	120	130	100
16.1.1992	170	140	210	160	110	110	120
Average	186	173	221	135	121	123	107

*) Values in brackets omitted when calculating average values.

Total dissolved solids (TDS) at Vingunguti waste stabilization ponds (26.11.1991 - 16.1.1992).

Date	Sampling points						
	AI	AO	I	FM_1	M_1M_2	M_2M_3	O
26.11.1991	400	460	415	370	350	360	445
28.11.1991	347	360	436	320	442	480	415
3.12.1991	472	320	376	342	361	347	483
5.12.1991	420	373	391	380	373	402	416
10.12.1991	417	361	387	420	375	416	362
12.12.1991	465	375	355	460	370	420	386
17.12.1991	380	(1020)*)	230	260	390	400	400
19.12.1991	390	(1200)	230	280	410	400	420
26.12.1991	2190	1100	300	290	360	370	340
31.12.1991	410	365	380	370	368	390	401
2.1.1992	670	1100	310	310	360	390	330
7.1.1992	4300	1090	270	330	390	400	470
9.1.1992	6390	1150	220	330	460	410	(700)
14.1.1992	350	(1210)	250	330	480	400	360
16.1.1992	430	(1200)	250	360	460	370	370
Average	1202	642	320	343	397	397	400

*) Values in brackets omitted when calculating average values.

Appendix 1 (2/5)

Fecal coliform (FC) counts at Vingunguti waste stabilization ponds (11.11.1991 - 9.1.1992).

Date	Fecal coliform (counts/100 ml) at point						
	AI	AO	I	FM_1	M_1M_2	M_2M_3	O
11.11.1991	350	85	-	116	269	38	1.8
13.11.1991	440	340	1265	104	296	23	2.2
26.11.1991	470	170	938	301	366	91	5.1
28.11.1991	420	940	1590	188	78	61	5.6
3.12.1991	490	160	1080	18	66	26	7.2
5.12.1991	-	1040	1920	98	78	97	19
10.12.1991	930	1070	1970	84	72	64	38
12.12.1991	1670	970	1920	92	112	102	23
17.12.1991	690	570	120	44	52	41	7
26.12.1991	540	970	1120	34	60	38	21.4
31.12.1991	640	990	1080	88	66	40	10
2.1.1992	530	180	600	22	48	34	12.4
7.1.1992	240	90	-	4	8	3	2.4
9.1.1992	390	480	1180	24	34	21	5.4
Average	600	575	1232	87	115	49	11.5

Fecal streptococci (FS) at Vingunguti waste stabilization ponds (11.11.1991 - 9.1.1992).

Date	Fecal Streptococci (counts/100 x 10^3 ml) at						
	AI	AO	I	FM_1	M_1M_2	M_2M_3	O
11.11.1991	6600	2725	-	1470	633	141	35.4
13.11.1991	4030	3950	3500	1030	1060	109	39
26.11.1991	1970	1900	-	340	378	181	35
28.11.1991	940	760	910	130	156	67	17
3.12.1991	410	320	-	66	128	22	12.2
5.12.1991	-	1610	1870	104	96	105	22
10.12.1991	1260	1630	1670	108	98	103	26
12.12.1991	490	210	1980	254	376	96	5.4
17.12.1991	960	660	-	104	112	71	12.2
26.12.1991	600	780	1440	40	28	48	18
31.12.1991	710	790	1610	49	30	50	17.5
2.1.1992	1370	980	2100	160	236	68	24
7.1.1992	370	240	-	32	18	21	9.6
9.1.1992	420	690	1480	32	54	34	7.8
Average	1548	1232	1840	280	243	80	20

Appendix 1 (3/5)

Ammonia (NH_3-N) concentration at Vingunguti waste stabilization ponds (11.11.1991 - 16.1.1992).

Date	Ammonia concentration at point						
	AI mg/l N	AO mg/l N	I mg/l N	FM_1 mg/l N	M_1M_2 mg/l N	M_2M_3 mg/l N	O mg/l N
11.11.1991	15.5	12.9	3.9	2.0	0.5	0.3	0.5
13.11.1991	17.8	18.3	5.5	1.2	0.8	1.0	1.2
26.11.1991	12.4	14.2	6.4	12.6	10.5	14.0	12.6
28.11.1991	9.2	12.3	13.4	12.6	10.7	10.4	7.6
3.12.1991	10.0	20.0	10.0	10.0	12.0	8.0	10.0
5.12.1991	11.0	12.0	10.0	10.0	11.0	9.0	11.0
10.12.1991	(20.0)*)	14.3	(20.0)	10.5	(20.0)	10.0	(25.0)
12.12.1991	7.0	8.0	7.0	9.5	9.0	6.5	6.5
17.12.1991	9.5	5.0	6.5	6.0	9.5	7.0	5.0
19.12.1991	8.0	7.5	8.0	6.0	9.0	6.8	6.0
26.12.1991	8.0	8.0	7.5	5.0	8.6	6.5	8.0
31.12.1991	9.0	12.0	12.5	9.5	9.0	7.0	7.0
2.1.1992	8.0	9.0	9.0	5.5	9.0	6.0	8.0
7.1.1992	8.0	5.0	7.5	7.0	6.6	7.0	6.0
9.1.1992	9.9	9.0	7.0	7.0	8.0	6.5	8.0
14.1.1992	7.5	7.0	7.0	8.0	9.0	9.0	9.0
16.1.1992	7.0	7.0	7.0	8.0	8.0	9.0	7.0
Average	9.8	10.1	8.0	7.7	8.2	7.3	7.1

*) Values in brackets omitted when calculating average values.

Nitrite (NO_2-N) concentration at Vingunguti Waste Stabilization ponds (26.11.1991 - 9.1.1992).

Date	Nitrite concentration at point						
	AO mg/l N	AI mg/l N	I mg/l N	FM_1 mg/l N	M_1M_2 mg/l N	M_2M_3 mg/l N	O mg/l N
26.11.1991	1.67	1.05	4.70	1.42	1.18	1.25	(3.28)*)
28.11.1991	0.95	0.83	1.24	0.87	0.69	0.87	(1.13)
3.12.1991	1.00	0.90	2.10	0.80	0.70	0.70	0.50
10.12.1991	1.05	1.25	1.50	1.20	1.50	1.50	1.25
12.12.1991	0.25	0.20	0.20	0.20	0.35	0.40	0.30
17.12.1991	0.60	0.20	0.20	0.20	0.60	0.50	0.20
19.12.1991	0.40	0.30	0.20	0.20	0.50	0.40	0.20
26.12.1991	0.40	0.30	0.30	0.20	0.30	0.30	0.20
31.12.1991	0.60	0.80	0.40	0.30	0.40	0.40	0.30
2.1.1992	0.40	0.20	0.20	0.20	0.30	0.30	0.20
7.1.1992	0.32	0.30	0.20	0.20	0.20	0.30	0.20
9.1.1992	0.30	0.24	0.20	0.20	0.20	0.20	0.22
Average	0.66	0.55	0.95	0.50	0.58	0.60	0.40

*) Values in brackets omitted when calculating average values.

Appendix 1 (4/5)

Nitrate (NO_3-N) concentration at Vingunguti waste stabilization ponds (28.11.1991 - 16.1.1992).

Date	Nitrate concentration at point						
	AI mg/l N	AO mg/l N	I mg/l N	FM_1 mg/l N	M_1M_2 mg/l N	M_2M_3 mg/l N	O mg/l N
28.11.1991	7.6	8.5	12.1	9.2	8.3	(11.3)*)	9.6
3.12.1991	10.5	10.5	10.5	8.5	7.8	6.9	6.0
10.12.1991	10.5	(20.0)	(20.0)	10.0	8.5	10.5	10.0
12.12.1991	9.0	8.5	10.0	8.5	7.5	9.0	6.0
17.12.1991	9.8	6.8	9.5	8.0	10.0	9.5	6.0
19.12.1991	9.0	9.5	9.0	7.0	10.0	9.0	6.5
26.12.1991	9.0	8.5	9.0	7.6	9.0	10.0	6.0
31.12.1991	10.0	9.5	10.5	8.5	8.0	8.5	7.5
2.1.1992	9.0	8.0	9.0	7.0	9.0	9.0	7.0
7.1.1992	6.0	5.5	7.0	5.3	5.0	6.0	5.4
9.1.1992	9.0	8.0	7.8	7.6	9.0	6.0	(6.8)
14.1.1992	8.0	7.5	9.0	7.5	9.0	8.5	9.0
16.1.1992	8.0	7.0	9.0	7.0	8.0	8.0	9.0
Average	8.8	8.2	9.4	7.8	8.4	8.4	7.3

*) Values in brackets omitted when calculating average values.

Concentration of copper (Cu) at Vingunguti waste stabilization ponds (17.12.1991 - 16.1.1992).

Date	Concentration of Copper at point			
	AI mg/l	AO mg/l	I mg/l	O mg/l
17.12.1991	1.00	(23.00)*)	9.00	1.00
19.12.1991	0.06	0.12	0.01	0.27
26.12.1991	0.80	0.10	0.01	0.12
31.12.1991	0.10	0.10	0.20	0.10
2.1.1992	0.50	0.10	0.05	0.19
7.1.1992	(4.00)	(6.00)	0.03	1.00
9.1.1992	3.00	2.00	7.00	1.00
14.1.1992	0.06	0.02	0.05	0.06
16.1.1992	0.07	0.04	0.08	0.06
Average	0.70	0.35	1.83	0.42

*) Values in brackets omitted when calculating average values.

Appendix 1 (5/5)

Concentration of chromium (Cr) at Vingunguti waste stabilization ponds (17.12.1991 - 16.1.1992).

Date	Concentration of chromium at point			
	AI mg/l	AO mg/l	I mg/l	O mg/l
17.12.1991	0.30	4.00	0.02	1.00
19.12.1991	1.00	0.03	0.03	2.00
26.12.1991	0.01	0.60	0.05	0.11
31.12.1991	1.00	0.10	0.01	0.10
2.1.1992	0.60	0.60	0.03	0.20
7.1.1992	1.00	1.00	1.00	1.00
9.1.1992	1.00	2.00	3.00	1.00
14.1.1992	0.04	0.01	0.07	0.01
16.1.1992	0.05	0.10	0.07	0.02
Average	0.56	0.94	0.48	0.60

pH values at Vingunguti waste stabilization ponds (11.11.1991 - 16.1.1992).

Date	pH values at points						
	AI	AO	I	FM_1	M_1M_2	M_2M_3	O
11.11.1991	7.5	7.6	6.9	8.1	8.2	9.1	8.8
13.11.1991	7.6	7.7	6.9	8.4	8.1	9.1	9.1
26.11.1991	7.7	7.8	6.8	8.4	7.6	8.5	9.4
28.11.1991	7.3	9.6	8.6.	7.8	7.5	8.9	8.2
3.12.1991	7.4	7.6	6.7	8.2	8.4	9.2	8.6
10.12.1991	8.7	9.6	9.0	8.2	7.6	8.3	8.6
12.12.1991	7.8	7.9	9.1	8.2	7.5	8.4	8.7
17.12.1991	7.4	7.6	7.2	8.0	7.6	7.8	9.0
19.12.1991	6.5	6.7	6.8	9.0	7.2	8.3	8.0
26.12.1991	6.8	6.9	6.7	8.5	6.6	7.7	7.8
31.12.1991	7.0	7.5	6.9	8.4	7.5	8.0	8.5
2.1.1992	7.5	6.7	6.0	6.8	6.4	6.3	6.5
7.1.1992	7.5	8.0	7.0	9.0	8.0	7.8	8.0
9.1.1992	7.5	7.8	7.4	7.5	9.0	8.0	8.0
14.1.1992	6.8	7.6	7.4	8.0	7.5	7.6	7.8
16.1.1992	6.8	7.5	6.5	8.5	8.0	8.0	7.6
Average	7.4	7.8	7.3	8.2	7.7	8.2	8.3

Appendix 2

Tanzania temporary standards for effluents meant for direct discharge into receiving waters (Tanzania Bureau of Standards 1988 cited by Howard Humphreys 1988).

Substance	Unit	Maximum permissible value
BOD_5	mg/l	30
TDS	mg/l	3000
FC	no./100 ml	5000
NH_3-N	mg/l	10
NO_3-N	mg/l	50
NO_2-N	mg/l	1.0
DO	mg/l	5.0
pH	-	6.5 - 8.5
Pb	mg/l	0.2
Zn	mg/l	1.0
Cd	mg/l	0.1
Cr	mg/l	0.1
Cu	mg/l	0.1
Ni	mg/l	0.2

Appendix 3

An example of a questionnaire sent to the industries contributing wastewater to Vingunguti waste stabilization ponds.

SURVEY OF INDUSTRIAL EFFLUENTS - QUESTIONNAIRE

Name of company: Tropical Foods Limited

Address or location: Plot no. 12, Vingunguti, Pugu Road

Number of shifts per day: 1 **Duration of shift:** 8 h

Work force per shift: 65

Canteen facilities: Yes

Water sources: National Urban Water Authority

Average water consumption: 20 m^3/d

Peak rate of consumption: - l/s

Goods manufactured or processed:

Canned and bottled food products

Processes employed in manufacture:

Raw material (fruits) ---> sorting ---> washing ---> sorting ---> juice extraction ---> blending/mixing ---> filling ---> processing (applying temperature and pressure)

Volume of process water discharged to waste: 5 000 l/d

Peak rate of wastewater discharge: - l/s

Future development plans including introduction of new processes: Extensions

Present treatment facilities: Nil

Present method of disposal of liquid waste:

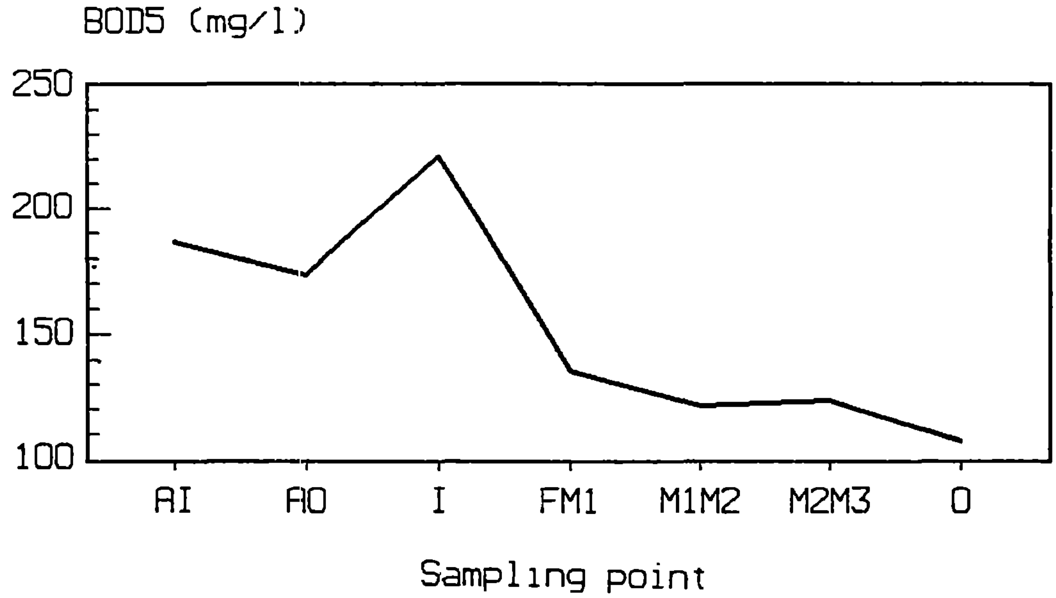
Sewerage system that goes to Vingunguti waste stabilization ponds

General observations: Nil

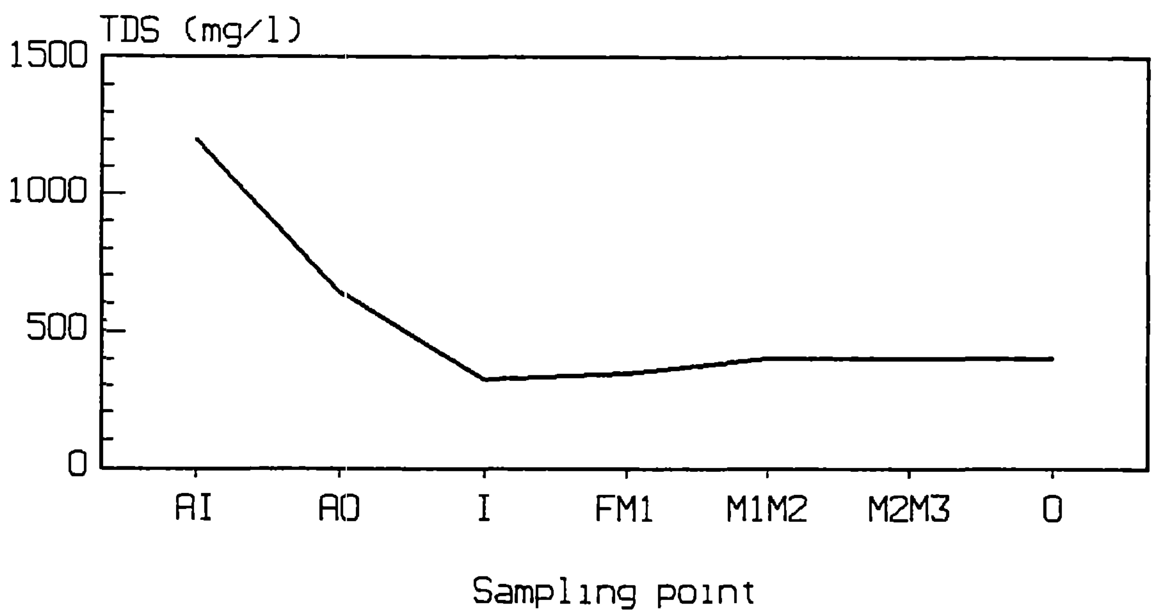
Name and position of person interviewed:

Mr Robert Mkangila / Factory Engineer

Date: 27.11.1991

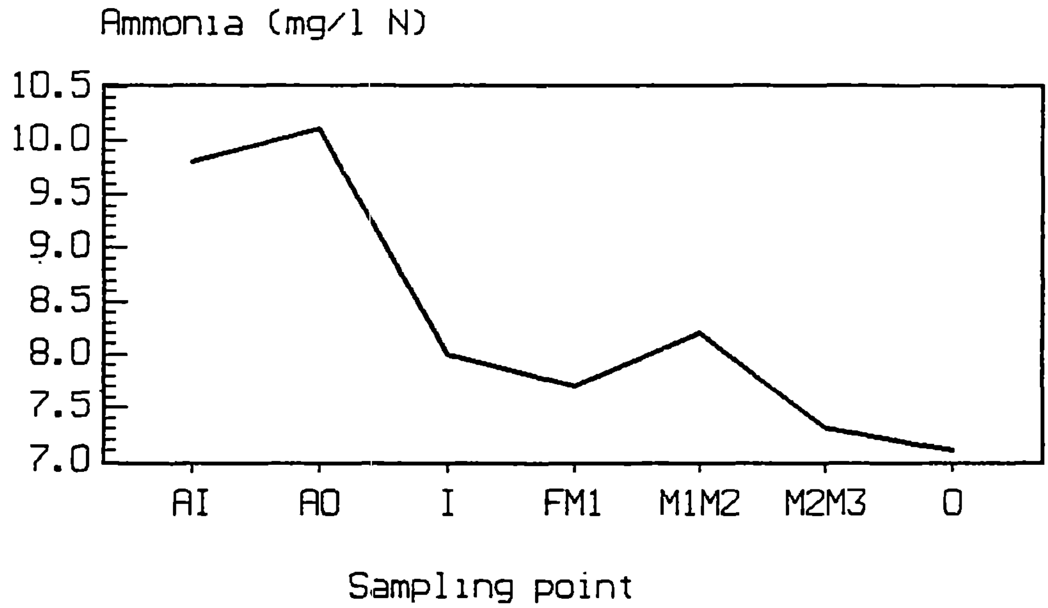


BOD_5 at Vingunguti waste stabilization ponds during 26.11.1991 - 16.1.1992.

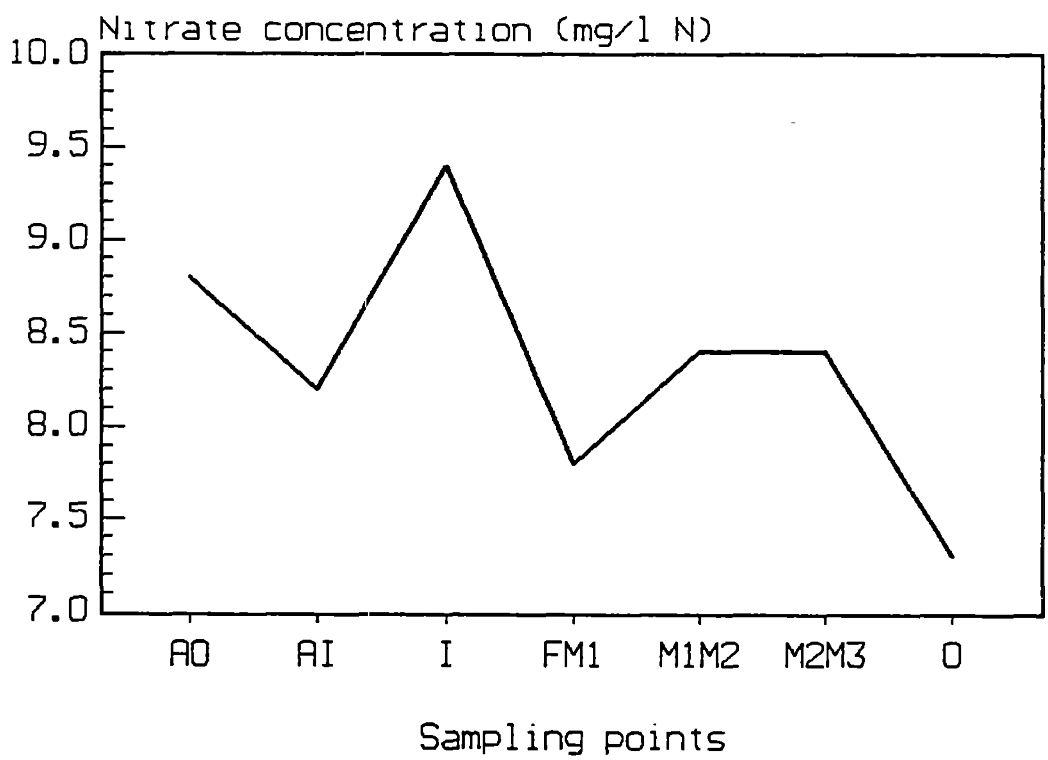


TDS at Vingunguti waste stabilization ponds during 26.11.1991 - 16.1.1992.

Appendix 4 (2/3)

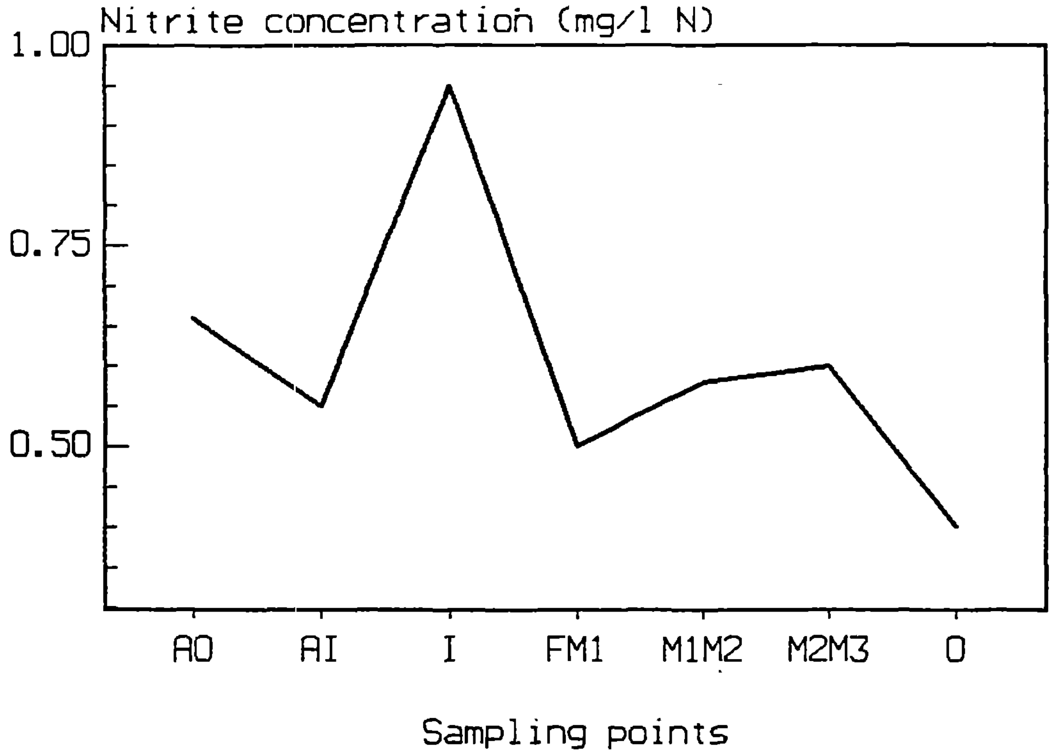


Concentration of ammonia at Vingunguti waste stabilization ponds (26.11.1991 - 9.1.1992).



Concentration of nitrate at Vingunguti waste stabilization ponds (26.11.1991 - 16.1.1992).

Appendix 4 (3/3)



Concentration of nitrite at Vingunguti waste stabilization ponds (26.11.1991 - 9.1.1992).