STRATIFICATION IN WASTE STABILIZATION PONDS I: EFFECTS ON POND PARAMETERS

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ABSTRACT

Stratification studies were carried out on the waste stabilization pond system at the University of Nigeria, Nsukka, Nigeria. Analysis of the samples collected with a water column sampler at 5cm and 0.1m apart showed some stratification of temperature, algae, pH, dissolved oxygen, coliform bacteria, chemical oxygen demand and nutrients. Coliform-bacteria numbers were lowest at positions in the water column where pH, temperature, dissolved oxygen and algae were high. The distribution and variation of both the physiochemical and biological characteristics inside the water body were found to be influenced by thermal stratification. Maximum temperature, DO and pH was observed at the surface layer. The vertical distribution of BOD_5, COD, Coliform bacteria, phosphorus and ammonia nitrogen showed maximum concentration at the bottom layer.

Keywords: Thermal stratification; coliform bacteria; waste stabilization pond; dissolved oxygen; chemical oxygen demand

INTRODUCTION

A wastewater stabilization pond is a relatively shallow body of wastewater contained in an earthen basin which is designed to treat wastewater. Although Waste Stabilization Ponds have small depths, their high turbidity provide favourable conditions for the occurrence of stratification, mainly during summer. During that time of the year, the layers nearest to the surface concentrate a larger amount of thermal energy compared to the deeper layers, which results in a temperature difference between the surface and the bottom of the pond. As a consequence a density profile appears, with the less dense layers located at the surface of the pond (the epilimnion) and the densest ones close to the bottom (hypolimnion) [1]. Between these two layers is a third layer (the metalimnion) where strong vertical differences (gradients) in temperature, and therefore density prevail. Stratification induces alterations in the flow pattern and a decrease of the useful volume of the pond. Some researchers believe that stratification aids in the development of a high pH zone and increases short circuiting which has the risk of shortening the pond retention time [2, 3].

Therefore, the importance of studying stratification in waste stabilization ponds are numerous. It helps in understanding the ponds better and aids in the formulation of more realistic models. The existence of stratification in ponds has a lot of implications on several aspects of pond design, sampling and operation.

Deep lagooning is an alternative to conventional lagooning and implies smaller land requirements as an additional advantage. The development of this kind of system is relatively recent, and its use is spreading through urban areas where the price of land is high, and through urban areas surrounded by rich agricultural land. The use of deep stabilization ponds as wastewater treatment systems may cause some functional problems related to thermal stratification, which makes the mixing processes difficult. The unusual depths may cause thermal stratification which makes the mixing processes along the vertical axis difficult, affecting the distribution of nutrients and dissolved oxygen in the water column.

With the new interest in deeper ponds to reduce the large land requirement of ponds [4, 5], greater attention is directed to the effect of stratification on pond performance [6-8]. The phenomena of stratification cannot be ignored in ponds since ponds are known to remain stratified over a period of time. According to Agunwamba [9], stratification may occur in ponds as shallow as 0.2m deep. Hence, the assumption of complete mixing in ponds may not be satisfied in all cases.

There are some field studies on stratification which have helped to advance the level of knowledge of this important phenomenon [3, 6, 8, 10, 11]. However, stratification has not been studied extensively in laboratory ponds. But such studies are necessary to investigate the effect of changes in temperature on pond parameters. Laboratory studies, unlike field studies, should give clearer indication of the important roles played by the various factors in isolation, while minimizing the interactive effects of the other factors.

The aim of this paper is the investigation of the effect of temperature changes on WSP parameters. For this research, a daily study of the treatment processes was conducted under different temperature ranges (25 to 40°C). The physicochemical parameters observed, were: temperature, dissolved oxygen (DO), hydrogen ion concentration (pH), detention time (8) suspended solids (SS), algal concentration (Cs), organic loading (OL), chemical oxygen demand (COD), concentration of coliform bacteria, Biochemical oxygen demand (BOD_5) Ammonia nitrogen, and phosphate.

MATERIALS AND METHODS

Full-Scales WSP

The full-scale WSP (123.3m x 27.lm x 0.2m water depth) studied is situated at the University of Nigeria, Nsukka campus and treats domestic wastewater of the campus community. The treatment plant consists of a bar rack, an imhoff tank, a drying bed for the digested sludge and two facultative WSPs for the effluent from the imhoff tank. Samples were collected from the second pond since the first were overgrown with grass.

Influent and effluent samples were collected between 7.00am and 8.00am at 0.05m interval of depth in the region of the inlet and outlet of the pond using a pond column sampler designed to obtain water samples from discrete layers in stratified water bodies [12,13].

Laboratory Scale WSP

Six rectangular units made of thick flat sheets, each measuring 2.0m x 0.5m x 0.4m were used for the study of the occurrence of thermal stratification. The vertical profile of the laboratory ponds is shown in Fig. 1 with pond A acting as a control while the rest are operated under different temperatures.

The inlet were connected to a flow inducers to obtain a constant influent flow. Feedlines of 19mm diameter (PVC) pipes with 19mm diameter gate valves to regulate the influent flow were connected from the ponds to a 500L polythene vessel capacity feed tank with a tee joint to enhance even distribution between all the ponds.

Two 500L polythene vessels with a stirrer were used as the feed tank to which feed lines were connected to facilitate continuous operation of the system. The feed tanks were placed at an elevation of 2m and 1.5m above the ponds as shown in Figure 1 to enable the wastewater enter the ponds through gravity and the influent drop freely into all the ponds. The effluent discharged through a 19mm diameter PVC pipes separated with 19mm diameter gate valves to minimize back flow. The experiments were conducted in the Department of Civil Engineering, University of Nigeria, Nsukka with illumination provided by a set of fluorescent bulbs fitted to a wooden stand. The system was set up for a few weeks to allow for attainment of steady state conditions.

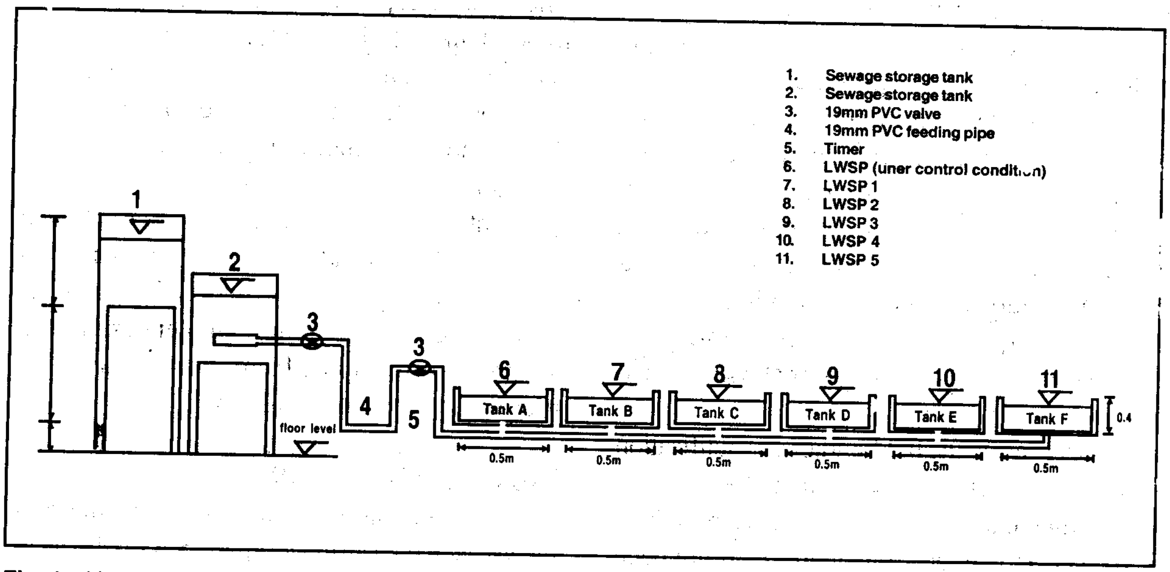

Fig. 1: vertical profile of LWSP for the study of thermal stratification

Laboratory investigation of thermal stratification in LSWSP were conducted by fixing thermostatically control heaters at the top layers of the Tanks C, D, E and F which resulted in the heating of the surface layers when current are flowing through the heating element, while the bottom layers remain colder. The water samples were collected at 0.1 m intervals in all the six Tanks using vertical column sampler and analysed for different parameters. All analyses were undertaken according to the procedures described in the Standard Methods for the Examination of water and wastewater [14].

Tracer studies involving the collection and analysis of 400 samples were performed in order to determine the hydraulic efficiency of each Tank and the dispersion number (d) were obtained by Levenspiel [15].

RESULTS AND DISCUSSION

The distribution and variation of both physicochemical and biological characteristics inside the water body have been found to be influenced by thermal stratification. The distribution and variation of dissolved oxygen (DO), pHs, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), suspended solid (SS), DO, pH, BOD_5, COD, SS, K, ammonia nitrogen, total phosphorus and Cs with depth were studied. The weekly variation of these parameters for the field waste stabilization pond (FWSP) are shown in Figures 2 to 4 while Figures 5 to 10 show variations of the parameters with depth.

Variations of Pond Parameters with Depth due to Temperature Changes

The continuous wastewater inflow in the system did not hinder the appearance of a marked stratification mostly during the months of December and January

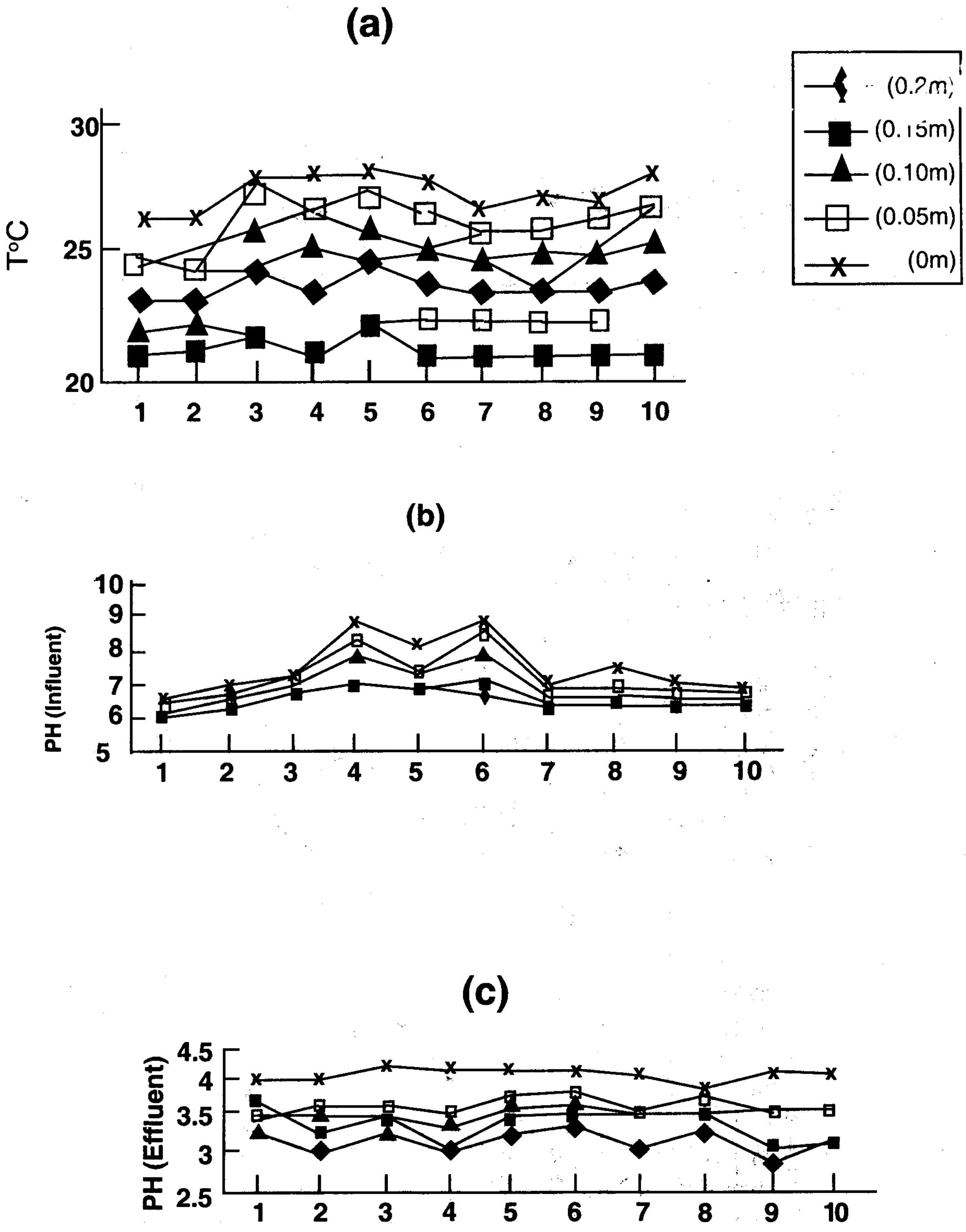

Fig. 2: Weekly Veriation of Temperature and PH in WSP at various depths.

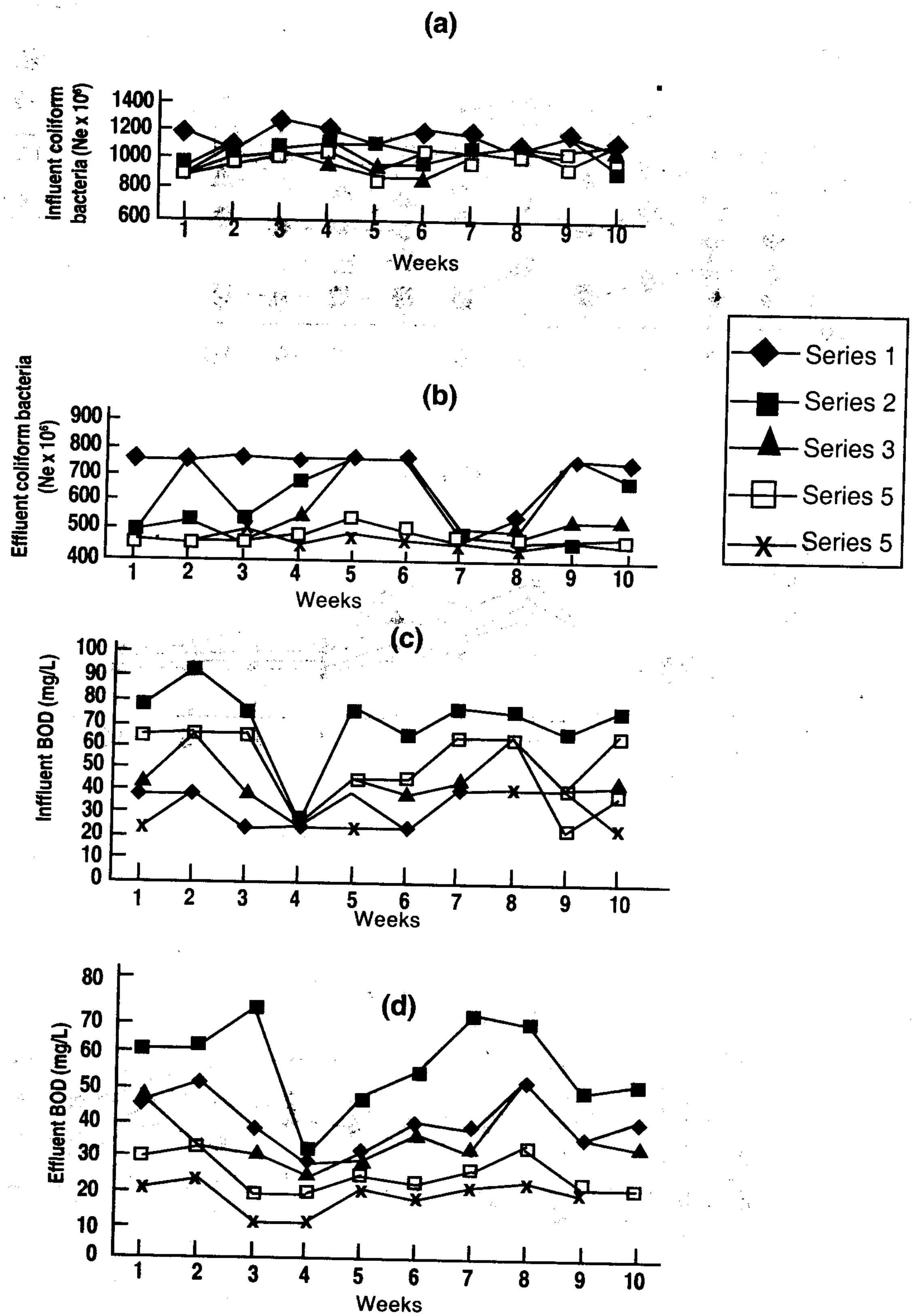

Fig. 3: Weekly variation of influent and effluent coliform bacteria concentration and BOD with depth.

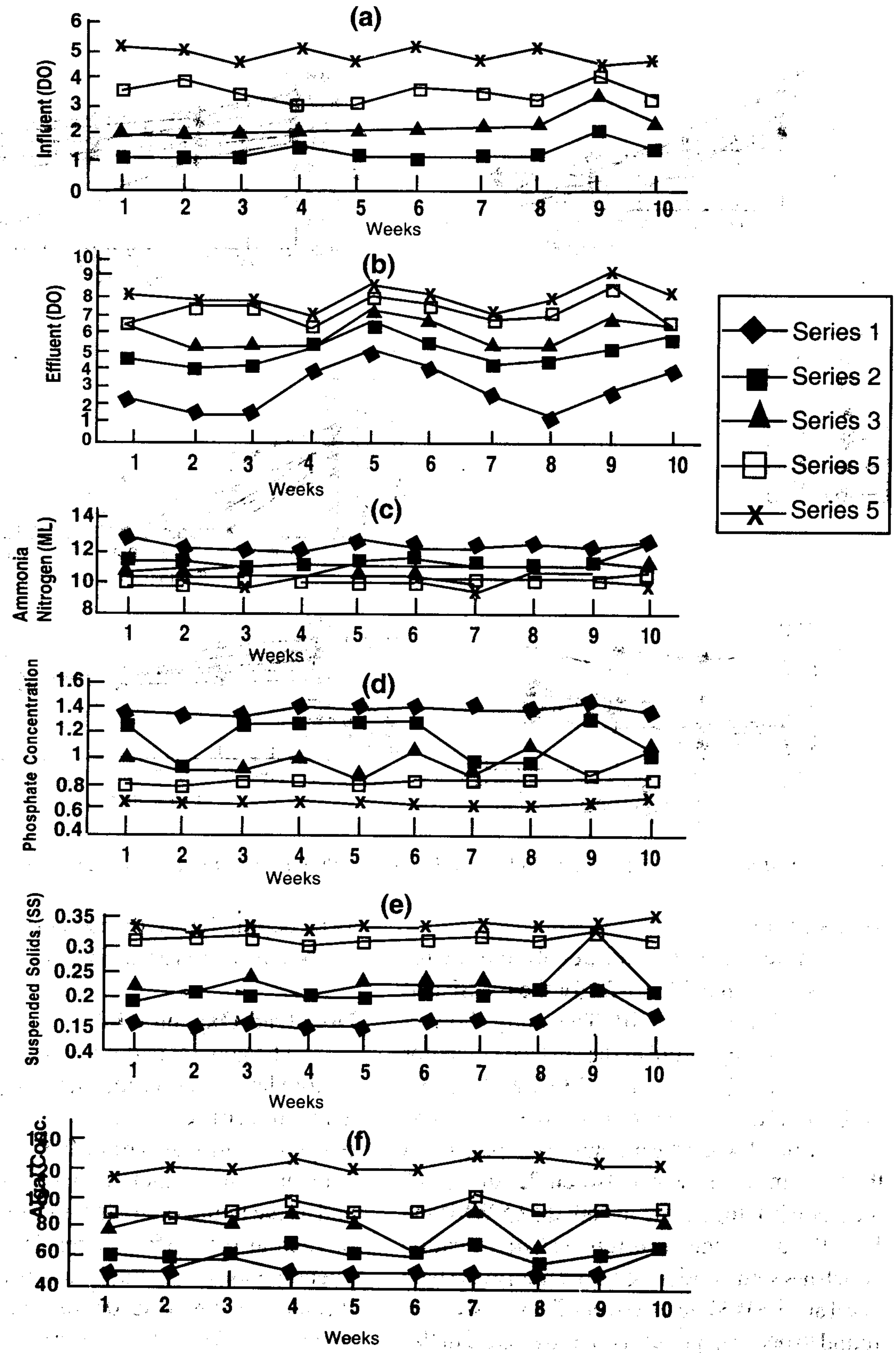

Fig. 4: Weekly variation of Influent and Effluent dissolved Oxygen (DO), Ammonia nitrogen, Phosphate, suspended solids and algal concentration in WSP at various depths.

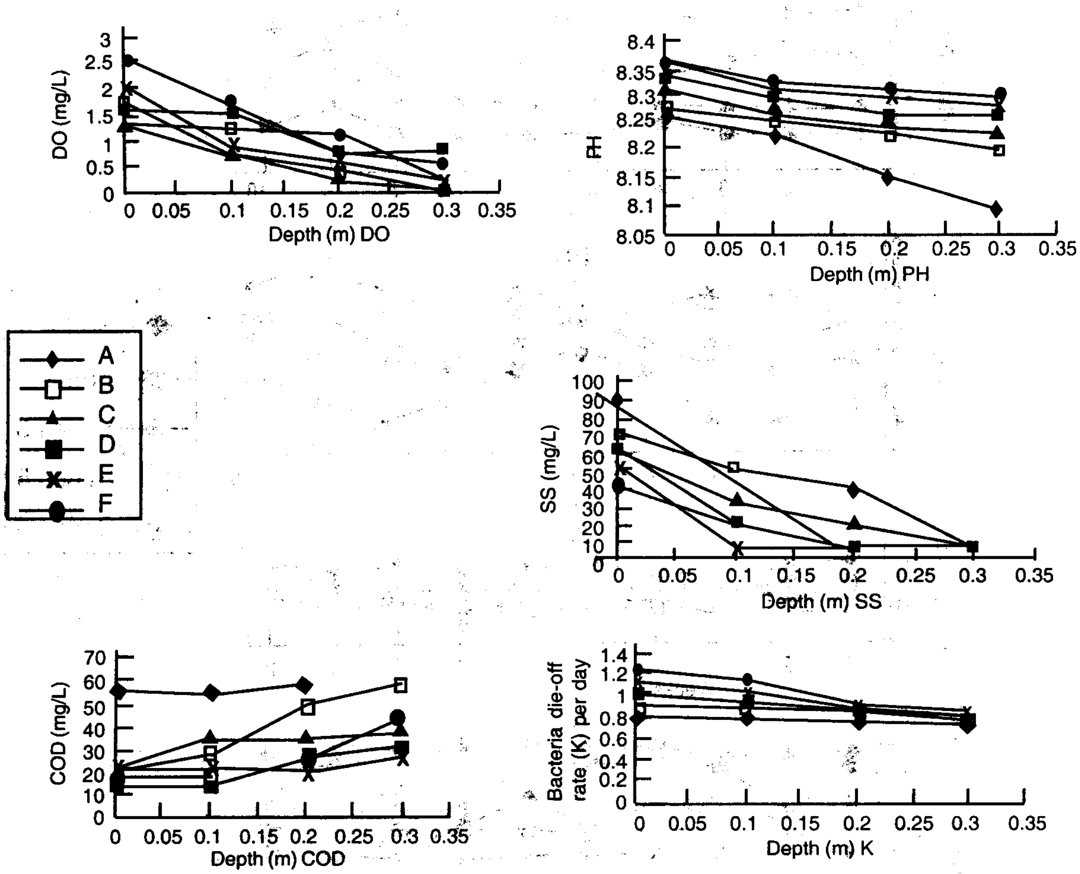

Fig. 5: Variation of DO, PH, T, SS, COD and K with depth due to temperature differences. (Day 1).

Temperature

The temperature profile evolved from this study are shown in Figure 2a for the FWSP and Figure 5c for the LSWSP. The study shows a maximum temperature at the surface layers for tanks A, B, C, D, E and F as 23°C, 25°C, 25°C, 30^{0}C, 35°C and 40^{0}C for the LSWSP and 28°C for the FWSP, while the minimum temperature at the bottom layers was between 22 and 23°C. Variation in temperature in both the LSWSP and FWSP indicate the occurrence of stratification which has stratification occurred both in the field pond and LSWSP respectively. Previously, been found to occur in ponds as shallow as 0.2m (9). No significant differences was found in the temperature observed at different points at the same depth, that is, the isotherms of the pond can be considered as horizontal.

Dissolved Oxygen (DO)

The general pattern was anaerobic at the bottom layer and aerobic at the surface layers. The anaerobic layer gets deeper as the temperature increases from Tank C to F as shown in Figures 5 to 10. DO was observed at all depths and as the temperature increases the dissolved oxygen at the surface layer decreases. This phenomenon can result in anaerobic condition throughout the pond depth. Maximum and minimum DO were 9.0mg/1 and 0.00mg/l for the FWSP and 3.04mg/l and 0.00mg/1 for the LSWSP.

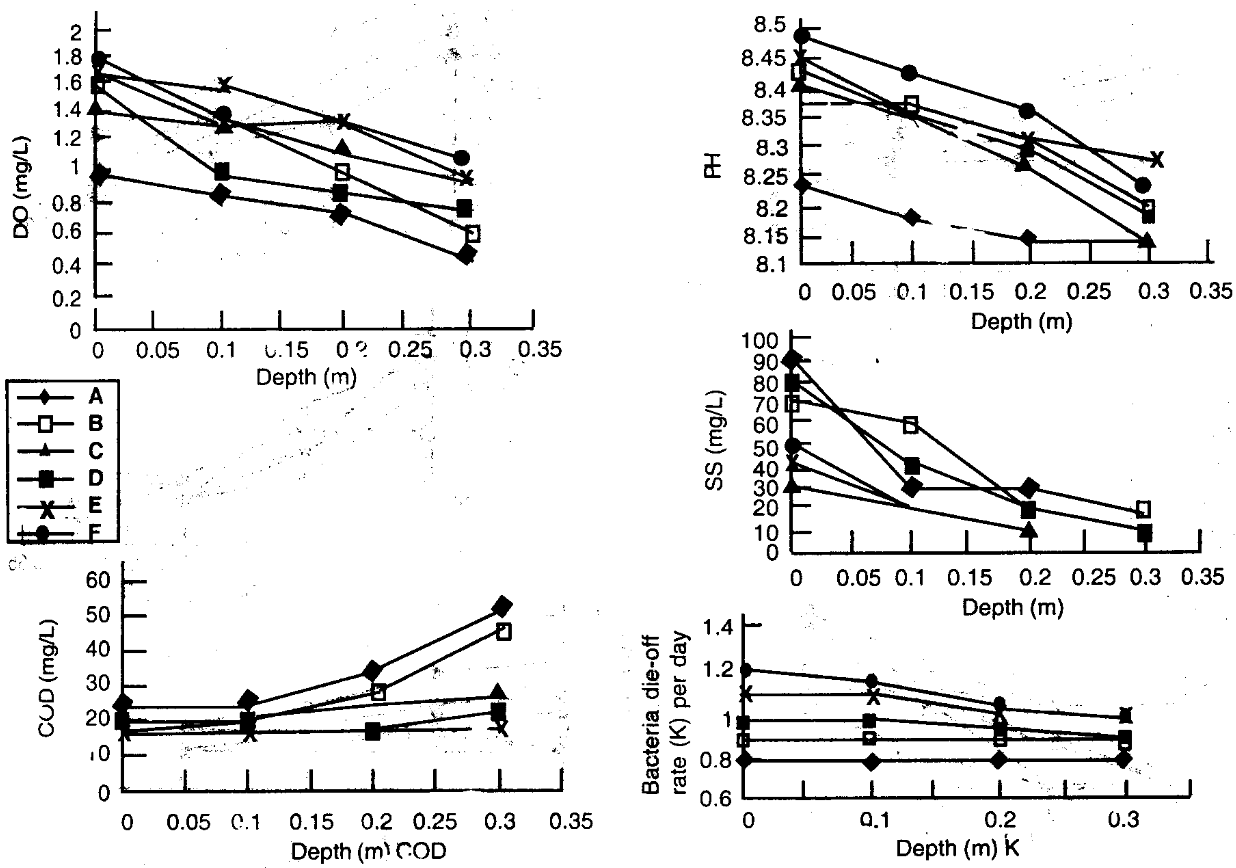

Fig. 6: Variation of DO, PH, T, SS, COD and K with depth due to temperature differences (Day 2).

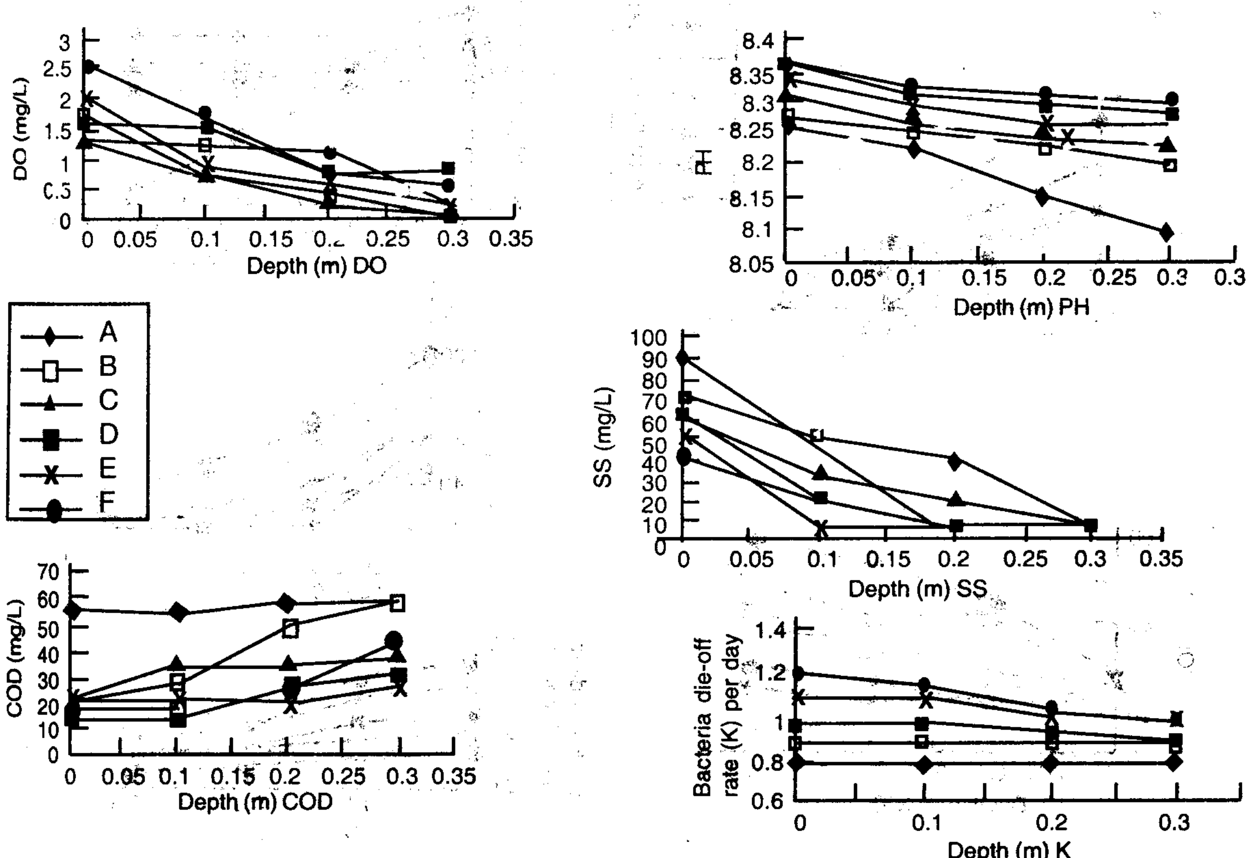

Fig. 7: Variation on DO, PH, T, SS, COD and K with depth due to temperature differences (Day 3).

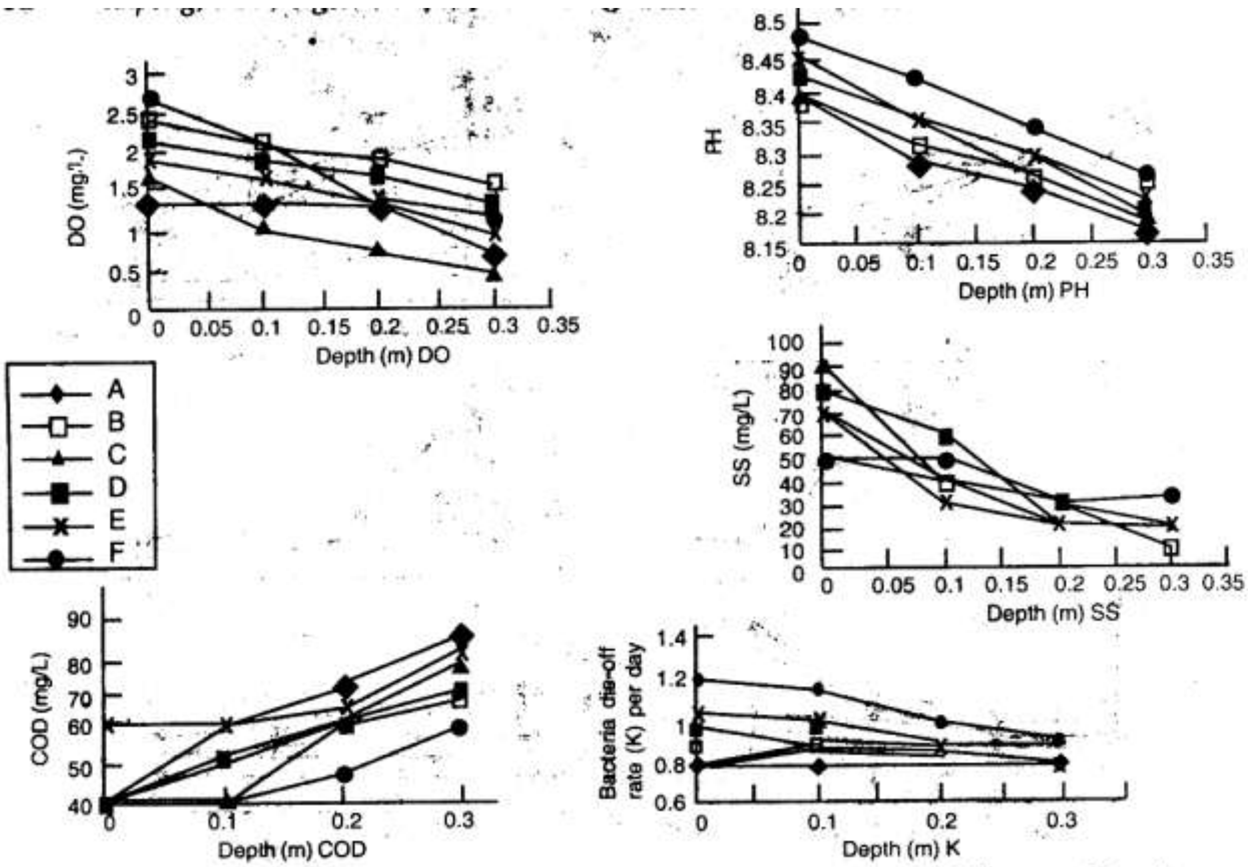

Fig. 8: Variation on DO PH T SS COD and K with depth due to temperature differences (Day 4).

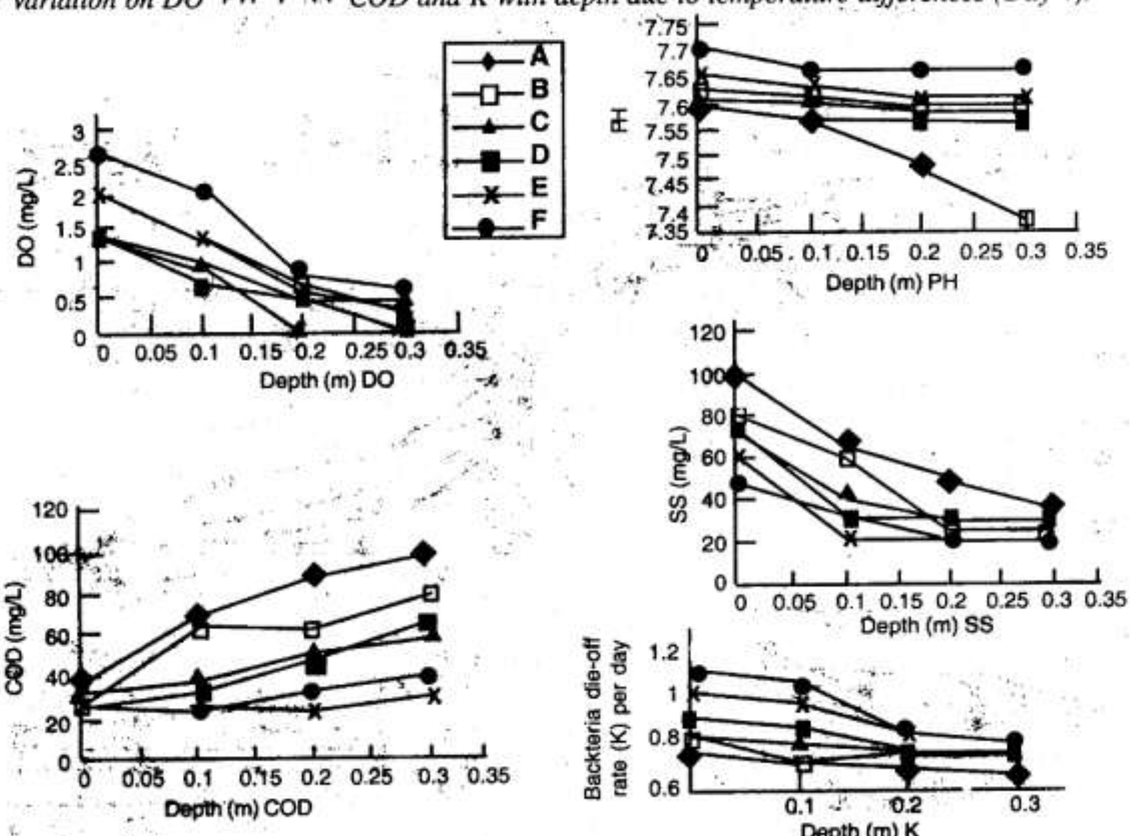

Fig. 9: Variation on DO, PH, T, SS, COD and K with depth due to temperature differences (Lay 5).

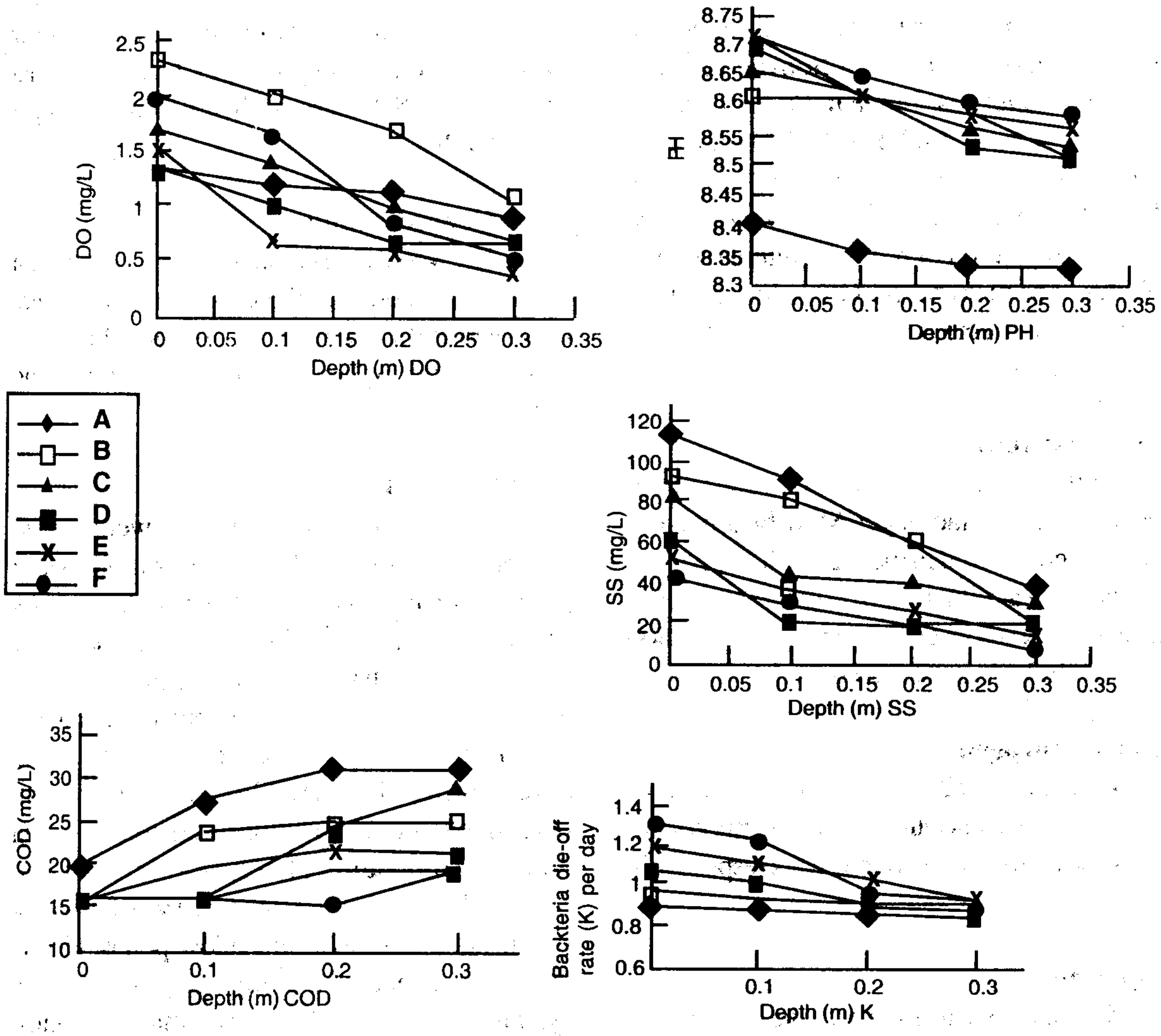

Fig.10: Variation on DO, PH, T, SS, COD and K with depth due to temperature differences (Day 6).

Hydrogen ion concentration (pH)

pH showed marked variation with depth. Photosynthesis controls the pH value at the surface while at the bottom layer (hypolimnion) the anaerobic degradation is the controlling factor of the pH evaluation. In this zone, pH values remained almost neutral, indicating an equilibrium between the acid and methanogenic phases of the fermentation. As shown in Figures 2b, 2c and 5 to 10, the presence of thermal stratification resulted in the variation of pH value throughout the whole water column. A great increase of pH at the surface layers was observed. Maximum and minimum pH values were 8.80 and 3.00 for the FWSP and 8.71 and 7.45 for the LSWSP.

Biochemical Oxygen demand(BOD)

The observed fluctuation of BOD along the vertical water column at all depths possibly resulted from the resuspension of the digested, previously sedimented particles by mixing within the pond. Hence thermal stratification resulted in the variation of BOD values within the vertical water column with the maximum value of 1149.5mg/l at the bottom and a mini mum value of 450mg/l at the surface layers as shown in Figures 3c, 3d and 5 to 10.

Chemical Oxygen Demand (COD)

The vertical distribution of COD was characterized by marked gradients of concentration. Maximum (l30mg/l) and minimum (16mg/l) COD occur at the bottom and surface layers respectively as shown in Figures *5* to 10. The occurrence of higher COD towards the bottom was due to the anaerobic re-dissolution and digestion of the matter previously sedimented and to the generation of reducing agents such as sulphides. The maximum COD reduction at the surface was associated with maximum DO, PH and temperature.

Coliform bacteria

Coliform bacteria was higher at the bottom layer than on the surface layer. More bicarbonates available were utilized in the metabolic activity of algae, causing a reduction of coliform bacteria. Coliform bacteria concentration ranged from 2400 to 3 per 100ml of samples analysed.

Ammonia nitrogen

Maximum (12.04mg/1) and minimum (10.29mg/1) ammonia nitrogen concentration were found at the bottom and surface layers respectively (Figure4c).

Phosphorus

Phosphorus was higher at the bottom but lower at the surface layers. The surface concentration was depleted by algae while the bottom quantity was enriched by precipitation of insoluble compounds. The concentration of phosphorus ranged from 1.32mgll to 0.62mg/l, being the maximum and minimum values respectively (Figure 4d).

Suspended Solids(SS)

Suspended solids *(SS)* showed significant variations throughout the LSWSP and field wastewater stabilization pond (Figures 4e and *5*- 10). The maximum and minimum SS values for the FWSP were 32.5mg/1 and *15.1*mg/1 while that of the LSWSP were 140mg/1 and 10mg/l respectively.

Algal Concentration

The weekly variation of algal concentration is shown in Figure 4f. Higher concentrations were observed at the top than the bottom which was associated to higher Dissolved oxygen at the surface layer.

CONCLUSION

Experimental investigations were carried out on both the field and laboratory waste stabilization pond system at the Nsukka Campus of the University of Nigeria, Nsukka. By sampling at depth intervals of 0.05m and 0.1 m in the field and laboratory scale ponds respectively under different temperature ranges and determining the pH, algal concentration, phosphorus, ammonia nitrogen, chemica1oxygen demand, biochemical oxygen demand and coliform bacterial concentration, it was found that stratification exists even in shallow ponds. Hence, the assumptions of a completely mixed flow system does not hold even for shallow ponds. Hence this result emphasizes the need to propose prediction models that could account for stratification and temperature variation in waste stabilization ponds.

However, further studies on the investigation of the occurrence of stratification based on hourly data collected at least for 24 hours in the summer as well as the winter should be carried out. This will enhance the level of understanding of the interaction between stratification and pond performance.

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