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Modelling the Effects of Baffles on the Performance of Waste Stabilization Pond Using 3-D Computational Fluid Dynamics

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ABSTRACT

A waste water stability pond is a relatively shallow body of wastewater contained in an earthen basin which is designed to treat wastewater. They are used to treat a variety of wastewater, from domestic wastewater to complex industrial wastewater, and they function under a wide range of weather conditions, that is, tropical to arctic. Investigation was made using a laboratory-scale pond to determine the effects of baffles on the performance of WSPs. The data from a lab-scale pond without baffles were compared against the one with the inclusion of baffles and analyses of the results were carried out to establish a relationship for the influence of baffles on pond performance. The model was run at steady state with raw wastewater to study the effects of baffles on the performance of WSP with constant area, depth, flow rate and hydraulic retention time (HRT). The model was operated with different rectangular shapes corresponding with different number of baffles; 0, 2 and 4 placed in each. BOD, DO concentrations and velocity distributions were determined for the different rectangular shape cases with different numbers of baffles. The treatment efficiency of the pond with or without baffles was studied for all given cases. Without baffles the effluent BOD concentration was found in the range of (235 - 252) mg/l for laboratory study while CFD model gave a range of (242 - 258) mg/l, with two baffles; the effluent BOD concentration was found in the range of (22.0 – 233) mg/l while CFD prediction gave a range of (29 - 241) mg/l. With four baffles, the effluent BOD concentration was found in the range of (12.0 – 55.0) mg/l, CFD model gave a range of (15 - 62) mg/l. The study has demonstrated that the BOD removal efficiency increased from 16% to 22% in case 1, from 22% to 92% in case 2 and from 82% to 96% in case 3. The DO effluent concentration decreased from 0.5mg/l to 0.26mg/l in case 1, increased from 6mg/l to 9.9mg/l in case 2 and increased from 9.5mg/l to 10.0mg/l in case 3. The results show that the presence of baffles improved WSP performance and this was aptly accounted for by the model.

KEYWORDS: Stabilization pond, modeling, computational fluid dynamics, baffles, concentration, effluent.

I. INTRODUCTION

Waste stabilization ponds (WSP) are cheap and effective way to treat waste water in a situation where the cost of land is not a factor. Not only has WSP been found to be one thousand times better in destroying pathogenic bacteria and intestinal parasites than the conventional treatment plants, [5] it is also more economical, [6]. It is simple to construct, operate and maintain and it does not require any input of external energy. Although a WSP system usually requires large land area because of its long detention time which is attributable to its complete dependence on natural treatment process, it will still be very suitable in several African countries and communities where land acquisition is not a problem. Besides, its efficiency depends on the availability of sunlight and high ambient temperature, which are the prevailing climatic conditions in most cases of these communities.

The treatment and disposal of wastewater in developing countries is of prime importance for environmental and public health reasons. The simplest method of municipal wastewater treatment is through the use of WSPs or lagoons. Lagoons are simple earthen basins in which wastewater treated by the removal of particulate matter and the biological degradation of settled solids. WSP rely on lengthy detention times and environmental factors such as wind and solar radiation for treatment efficiency. In addition, to being useful in the treatment of sewage WSP is applied in the treatment of industrial and agricultural wastes. Its long detention times, its relatively slow rates of sludge accumulation and its physico-chemical conditions such as neutrality to alkaline pH make it attractive in treating industrial wastewater. Besides, in maturation ponds, aerobic conditions promote complexion and precipitation of heavy metals. Ponds have been successfully used to treat industrial wastes high in copper and group II metals, wastes from palm oil and natural rubber industries and for polishing wastewater from activated sludge plants and tricking filters.

WSPs are becoming increasingly popular wastewater treatment option in many parts of the world. It is a man-made pond for the degradation of organic matter by bacteria and destructions of pathogenic organism by natural processes with limited control in wastewater before discharging into natural water courses. Therefore WSP are shallow basins of very large areas that are enclosed by embankments which are designed specifically for the treatment of wastewater by an entirely natural process involving both algae and bacteria. They are mainly used in tropical and sub-tropical regions where there is abundance of sunlight and the ambient temperature is normally high. The advantages of WSPs include simplicity, low cost, minimum maintenance and high efficiency. They are shallow man-made basins into which wastewater flows and from which after a retention time of several days (rather than several hours in conventional treatment processes), a well-treated effluent is discharged. However, it requires a large land area and this is their principal disadvantage. In WSP, treatment occurs through natural, physical, chemical and biological processes and no machinery or energy input (except the sun) is required. Treatment of the sewage is accomplished by bacteria and algae working together to break down the bacteria. The lighter, suspended material is broken down by bacteria in suspension. In this process carbon dioxide is given off.

WSP are simple earthwork structures open to the sun and air, which constitute the natural resources on which they can draw to accomplish their mission. Wastewater treatment by stabilization pond is a low cost but highly effective procedure. They are systems for the storage and treatment of sewage. The natural combination of oxygen using bacteria and oxygen producing algae occurring in such ponds convert the organic wastes into stable end products and produce a final effluent which can be discharged to the nearest acceptable drainage course. Where no discharge is possible, effluent may in certain cases be used to irrigate crops or simply be allowed to evaporate. In several countries, wastewater is generally too valuable to waste, and the reuse of pond effluents of crop irrigation or for fish culture is very important in the provision of high quality food. In a semi-arid zone, the use of wastewater storage and treatment reservoirs are advantageous as they permit the whole year's wastewater to be used for irrigation, thus enabling the irrigation of a much larger area and consequently much higher crop production.

WSP is a bio-chemical reactor whose main function is to remove pollutants and pathogens present in influent sewage. It is a shallow excavation which receives a continuous flow of wastewater. Adequate penetration of sunlight to all parts of the pond encourages algae growth. As the wastewater enters the pond, the heavier solids settle and form a sludge layer where they pass to anaerobic digestion. WSP may therefore be defined as man-made pond for the degradation of organic matter by bacteria and destruction of pathogenic organisms by natural processes with limited control in wastewater before discharging into natural water courses. The difference between it and other treatment methods is that no aeration equipment is required and the oxygen needed is provided by natural surface aeration and algae by photosynthesis. During the process of photosynthesis the algae release oxygen needed by aerobic bacteria. The oxygen released by the algae as a result of photosynthesis is utilized by bacteria for aerobic degradation or organic matter, the products, carbon-dioxide, ammonia and phosphate are in turn utilized by algae. WSPs are most feasible where large areas are available at low cost. They compromise a series of shallow lakes through which the sewage flows. A number of these are required, generally arranged in series such that successive ponds receive their flow from the previous pond. The most common arrangement of ponds is to have an anaerobic pond together with a facultative pond arranged in series and followed by a number of maturation ponds, although other arrangements are possible.

Ponds are classified as facultative, maturation, anaerobic, high rate and aerated common type of biological activity that takes place in them. The most common type of oxidation pond employed in wastewater treatment is the facultative type which is under aerobic and anaerobic conditions, whilst aerobic oxidation is predominant at the upper layers where the sunlight penetrates anaerobic oxidation exit towards the bottom layer, because the upper layers have more oxygen from algae production of oxygen by photosynthesis. Oxygen is also dissolved from the atmosphere at the lagoon surface. Hence, a large ratio of surface area to volume of liquid is desirable.

Disposal of oxygen in the pond also depends on mixing of the contents. The oxygen concentration is uniformly dispersed throughout the pond depth during mixing of the contents. But during stratification, oxygen is only found in the upper layers of the pond, the remaining part being under anaerobic condition. A situation arises where, during summer, the wind velocities are insufficient to break the stratification, algae concentration becomes low and the rate of oxygen produced is low and also oxygen is not dispersed throughout the pond. At the time the BOD feedback from the sludge is high, the rate of oxygen depletion is also high. If the reduced oxygen capacity is insufficient to meet the increased oxygen demand, the pond turns anaerobic. Even where the pond does not turn anaerobic, sludge rising to the surface may result in an odour problem. Mixing provides greater uniformity of the wastewater in the WSP to reduce variations that may cause process upsets of the micro-organisms and diminish treatment efficiency. At low temperature, the biological activities decreases and the pond contents are generally well maintained owing to wind effects. Ponds are the cheapest and simplest of all treatment technologies and are capable of providing a very high quality effluent. In particular, they can reduce levels of pathogenic micro-organisms well below those obtained by other types of treatment. The effluent from a properly designed series of ponds may contain less than 100 faecal coliforms per 100ml. An effluent of this quality may be used for unrestricted irrigation, [7]. Stabilization ponds are one of the cheapest treatment methods which can be employed for sewage treatment in developing countries. Some of these methods have sewage treatment efficiencies which are higher than those of the conventional methods in the developed countries. It can achieve about 99.99% efficiency in bacteria kill, [8]. The various operations involved in WSP are sedimentation, oxidation, digestion, gas exchange and photosynthesis. In addition, operation and maintenance expenses are generally much lower than those of the conventional treatment plants.

II. EFFECTS OF BAFFLES ON THE PERFORMANCE OF WASTE STABILIZATION PONDS

The performances of baffles in waste stabilization ponds (WSPs) have been evaluated and several researchers have found that the addition of baffles to WSPs could improve treatment efficiency [9]; [11]; [10]; [1]. Baffles are walls used to channel or direct the flow of wastewater through the ponds. These baffles would provide additional submerged surface area to which microorganisms could attach themselves, thus increasing the concentration of microorganisms in ponds and, theoretically, the rate of organic stabilization as well.

[12] Undertook an in-depth study on horizontal, vertical and longitudinal baffles. Three different lengths of baffles were tested: 50%, 70% and 90% pond width. Each of the lengths was tested in the ponds by using two, four, six and eight evenly spaced baffles. Short circuiting problems were found to occur in the 50% pond width when more baffles were used. Baffles of 70% width gave superior performance compared to the 50% and 90% baffle width. Increasing the baffle width to 90% was found to give a lower hydraulic efficiency than was seen with the 70% width baffles. [12], believed that this was due to the narrow channel created at the end of the baffles that increased the velocity of the fluid in this area. Further investigation on vertical baffles with four experiments was performed: two with four baffles and the other two with six baffles. It was discovered that the four baffle cases proved to be more efficient than the six baffle cases. This was attributed to channeling effects. However, when the results were compared against the horizontal baffle experiments, it was found that the horizontal configuration was more efficient. The comparison of the horizontal baffling and the longitudinal baffling gave the same result.

The effect of baffles on the treatment and hydraulic efficiency of a laboratory-scale waste stabilization pond was investigated by [13]. The dimensions of the laboratory scale pond were 1m long, 0.5m wide and 0.1m deep. Baffles were fitted along the longitudinal axis of the pond. The unbaffled laboratory scale pond was used as a control of the experiment. Although the publication did not specify the length of baffles that were used in the pond, the study investigated three, six and nine baffle ponds respectively. The treatment performance of the pond was assessed by observing the dispersion number, the effluent BOD and COD concentration in the pond effluent. It was noted that BOD removal increased with increased number of baffles. However, there was no significant improvement in the COD removal when baffles were installed in the pond. The BOD removals in the three, six and nine baffle ponds were 81%, 86% and 89% respectively while that of COD were 84% and 84.2% respectively. The results of the dispersion number in the three, six and nine baffle ponds were 0.126, 0.112 and 0.096 respectively indicating the initiation of plug flow pattern with increasing number of baffles. The baffled-laboratory pond developed isothermal condition due to the shallow depth (0.1m) that was used and this eliminated the effects of thermo-stratifications on the performance of the baffled ponds. The results indicated that ponds can be fitted with baffles to enhance the hydraulic performance without the risk of BOD overloading being initiated in the first baffle compartment.

Investigation into the treatment performance of complex ponds arrangement was carried out by [14]. The ponds comprised of five-series waste stabilization ponds that employed different geometry, depth and the hydraulic retention times. Two anaerobic ponds were operated at volumetric loading of 187g BOD per m^3 per day while the secondary facultative pond was operated at the surface organic loading of 217kg BOD per ha per day. One of the tertiary maturation ponds were fitted with baffles such that the ratio of the effective length: breadth was greater than 100:1. It was observed that this baffled maturation pond was more efficient at faecal coliform removal than other tertiary maturation ponds. Although the results of the baffled maturation ponds were encouraging, conclusions could not be drawn to suggest that the treatment performance of baffled primary facultative ponds could be similar to that of baffled maturation ponds. It was known that the hostile environmental conditions that remove faecal coliforms in maturation ponds were different from those found in facultative ponds. The investigation showed that baffles can improve significantly the treatment efficiently and hydraulic performance of facultative ponds. This can be one area of optimizing classic design methods in reducing the land area requirements for the construction of waste stabilization ponds. [9], evaluated the performance of baffles in waste stabilization pond comprising three laboratory-scale ponds with different number of baffles and one control unit without baffle. The study was aimed at promoting WSP practice for wastewater treatment in tropical countries by reducing the land area requirement through the use of baffles. The dimensions of the laboratory scale pond were 1.5m long, 0.5m wide and 0.15m deep and neglected thermo-stratification effects due to its shallow depth. It was revealed that the dispersion number decreased with increasing length and number of baffles, which indicated more plug flow conditions. The laboratory-scale pond was investigated with zero, two, four, and six baffle configurations corresponding to the biofilm surface area of 1.35, 2.15, 3.03 and 3.92 m^2 respectively.

The deviation of actual hydraulic residence time (HRT) from theoretical hydraulic residence time was computed and the flow pattern suggested the existence of an optimum spacing of baffles in baffled waste stabilization pond units. The hydraulic efficiency and physiochemical parameters were used to assess the treatment performance of the baffled ponds. It was observed that the hydraulic efficiency in the pond increased with increasing number of baffles. TN, NH_3-N and COD removal was increasing with number of baffles in the BWSP units with its maximum removal efficiency at six baffles. Faecal coliform die-off was also increased with increasing number of baffles in the order of 2-4 log removal. It was concluded that the treatment performance of waste stabilization ponds can be increased significantly by installing baffles.

[11] and [2] adopted the findings of [12] in respect of the use of 70% pond width baffles. A 2D-CFD model was used to access the treatment performance of the baffled facultative pond. It was found that faecal coliform removal in the pond increased with the number of baffles installed along the longitudinal axis of the pond. Faecal coliform removals of 4.22-5.92 log units were obtained in a primary facultative pond with 2 – 4 baffles. For these cases, the widths of flow channel with baffle compartments were greater than the width of flow channel at the baffle openings. Simulations of ponds with a large number (ten or more) of conventional baffles were not undertaken because the anticipated high effluent quality cannot be economically justified. However, research into baffled facultative ponds with a large number of 70% pond width baffles was very significant because performance assessments of the initiated plug flow pond can be evaluated against possible pond failure due to BOD overloading in the first baffle compartment. In addition, this configuration of baffled pond may form a width of flow channel in baffle compartments that is less than the width of flow channel at the baffle openings. In this situation stagnations can develop in the baffled pond due to a reduction of velocity magnitude of the baffle opening. This may reduce the effective pond volume and may reduce the expected pond performance. Other researchers [15]; [16], have also observed that baffles improve the hydraulic and treatment efficiency of waste stabilization ponds. The hydraulic efficiency and physicochemical parameters were used to assess the treatment performance of the baffled ponds. It was observed that the hydraulic efficiency in the pond increased with increasing number of battles. [4], identified that current design procedure for waste stabilization

ponds were not modified to include the improvement in the treatment efficiency and hydraulic performance that is initiated when baffles of various configurations are fitted in the pond and this will be part of the investigations in this research.

III. METHODOLOGY

Sources of data

The data requirement for the validation of the CFD model developed were obtained from literature of a full-scale field pond (WSP) located at the University of Nigeria, Nsukka, Enugu State [3] and from a published work of a laboratory-scale model [2]. The data analyzed for both the field pond and LSWSP were: : temperature (T^oC); dissolved oxygen (DO); hydrogen ion concentration (P^H); detention time (t); dispersion number (d); suspended solid (SS); algal concentration (Cs); organic loading rate (OL); faecal coliform per 100ml, the pond settling velocity (V); the maximum pond velocity under no wind (Um); the mean velocity of flow in the pond (U); biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

Laboratory Scale WSP (LSWSP)

Six rectangular units made of thick flat sheets all with the same dimensions measuring 2.0m, 0.5m and 0.4m; length, width and depth, respectively were used in the experimental work to study the performance of waste stabilization pond. In each case, one of the rectangular unit, served as the LSWSP operated under control conditions while the three others were operated under different ambient conditions. Both the control and the other LSWSP experiments were carried out with the four ponds connected in series using continuous flow process. The LSWSP inlets were connected in series to a flow inducer to obtain a constant and continuous influent flow. Feed lines of 19mm diameter (pvc) pipes with 19mm diameter gate valves to regulate the influent flow were connected from the ponds to the 500L polyethylene vessel capacity feed tank with a tee joint to enhance even distribution between all the ponds.

Determination of the effect of baffles on WSP performance

Investigation was made using the laboratory-scale ponds to determine the effects of baffles on the performance of WSPs. The data from a lab-scale pond without baffles were compared against the one with the inclusion of baffles and analyses of the results were carried out to establish a relationship for the influence of baffles on pond performance. The model was run at steady state with raw wastewater to study the effects of baffles on the performance of WSP with constant area, depth, flow rate and hydraulic retention time (HRT). The model was run with different rectangular shapes corresponding with different number of baffles; 0, 2 and 4 placed in each. BOD, DO concentrations and velocity distributions were determined for the different rectangular shape cases with different numbers of baffles. The treatment efficiency of the pond with or without baffles was studied for all given cases.

Modeling the effects of baffles on WSP performance

The effect of baffles was modeled using the 3-D CFD model as shown below;

$$Dx\frac{\partial^2 C}{\partial x^2}+D_y\frac{\partial^2 C}{\partial y^2}+D_z\frac{\partial^2 C}{\partial z^2}-\frac{U\partial C}{\partial x}-\frac{V\partial C}{\partial y}-\frac{W\partial C}{\partial z}-KC=0 \qquad 3.1$$

Writing the finite difference scheme,

$$\frac{\partial^2 C}{\partial x^2}=\frac{C_{i+1,j,k}-2C_{i,j,k}+C_{i-1,j,k}}{h^2}, \qquad \frac{\partial^2 C}{\partial y^2}=\frac{C_{i,j+1,k}-2C_{i,j,k}+C_{i,j-1,k}}{p^2}$$

$$\frac{\partial^2 C}{\partial z^2}=\frac{C_{i,j,k+1}-2C_{i,j,k}+C_{i,j,k-1}}{l^2}, \qquad \frac{\partial C}{\partial x}=\frac{C_{i+1,j,k}-2C_{i,j,k}+C_{i-1,j,k}}{2h}$$

$$\frac{\partial C}{\partial y}=\frac{C_{i,j+1,k}-2C_{i,j,k}+C_{i,j-1,k}}{2p}, \qquad \frac{\partial C}{\partial z}=\frac{C_{i,j,k+1}-2C_{i,j,k}+C_{i,j,k-1}}{2l}$$

$$Dx\left[\frac{C_{i+1,j,k}-2C_{i,j,k}+C_{i-1,j,k}}{h^2}\right]+Dy\left[\frac{C_{i,j+1,k}-2C_{i,j,k}+C_{i,j-1,k}}{p^2}\right]+$$

$$Dz\left[\frac{C_{i,j,k+1}-2C_{i,j,k}+C_{i,j,k-1}}{l^2}\right]-U\left[\frac{C_{i+1,j,k}-2C_{i,j,k}+C_{i-1,j,k}}{2h}\right]-$$

$$V\left[\frac{C_{i,j+1,k}-2C_{i,j,k}+C_{i,j-1,k}}{2p}\right]-W\left[\frac{C_{i,j,k+1}-2C_{i,j,k}+C_{i,j,k-1}}{2l}\right]-C_{i,j,k}=0$$

Rearranging the expression, it becomes;

$$\left(\frac{Dx}{h^2}-\frac{U}{2h}\right)C_{i+1,j,k}+\left(\frac{Dx}{h^2}-\frac{U}{2h}\right)C_{i-1,j,k}+\left(\frac{Dy}{p^2}-\frac{V}{2p}\right)C_{i,j+1,k}+$$

$$\left(\frac{Dy}{p^2}-\frac{V}{2p}\right)C_{i,j-1,k}+\left(\frac{Dz}{l^2}-\frac{W}{2l}\right)C_{i,j,k+1}+\left(\frac{Dz}{l^2}-\frac{W}{2l}\right)C_{i,j,k-1}-$$
$$\left(\frac{2Dx}{h^2}+\frac{2Dy}{p^2}+\frac{2Dz}{l^2}+K\right)C_{i,j,k}=0 \qquad 3.2$$

For the outlet end of the baffle, the boundary condition may be expressed as;

$$\frac{\partial C}{\partial x}=0, x=L$$

A finite divided difference can be written as:

$$\frac{C_{i+1,j,k}-C_{i-1,j,k}}{2h}=0$$

It implies that

$$C_{i+1,j,k}=C_{i-1,j,k}$$

Substitute this result in equation (3.2).

Also,

$$\frac{\partial C}{\partial x}=\frac{\partial C}{\partial z}=0, \qquad 0\le Z\le d$$

The finite divided difference can be written thus

$$\frac{C_{i+1,j,k}-C_{i-1,j,k}}{2h}=\frac{C_{i,j,k+1}-C_{i,j,k-1}}{2l}$$

This implies that

$$C_{i+1,j,k}=C_{i-1,j,k}$$
$$C_{i,j,k+1}=C_{i,j,k-1}$$

Inspection of this equation leads us to conclude that

$$C_{i+1,j,k}\equiv C_{i,j,k+1}$$
$$C_{i-1,j,k}\equiv C_{i,j,k-1}$$

By multiplying the above expression with a coefficient as a function of dispersion, velocity and mesh size in that direction, an approximate value can be obtained. That is.

$$C_{i+1,j,k}\approx C_{i,j,k+1}$$
$$C_{i-1,j,k}\approx C_{i,j,k-1}$$

Substitute this result in equation 4.60 for $0\le Z\le d$ representing the upper and lower layers of the pond.

Therefore, at the baffle's outlet, we have

$$2\left(\frac{Dx}{h^2}+\frac{Dz}{l^2}\right)C_{i-1,j,k}-\left(\frac{Dy}{p^2}-\frac{V}{2p}\right)C_{i,j+1,k}-\left(\frac{Dy}{p^2}-\frac{V}{2p}\right)C_{i,j-1,k}-$$
$$\left(\frac{2Dx}{h^2}+\frac{2Dy}{p^2}+\frac{2Dz}{l^2}+K\right)C_{i,j,k}=0 \qquad 3.3$$

Computational approach

Equation 3.3 was incorporated in the finite difference computational scheme for the pond with baffle(s) to take care of its effects on the overall pond performance. The presence of baffle(s) divides the pond into several numbers of cells depending on the number of baffles inserted. The equation took care of the exit condition from the end of the baffle's wall to the next cell, since the purpose of the baffle was to increase the detention time of wastewater concentration in the pond, allowing more time for bacteria activities to degrade available organic matter in the wastewater and thereby improving the efficiency of the pond. The approach was such that at every outlet position from each cell through the baffled ends, the computational scheme was written using equation 3.3 and it took care of the exit condition at that point in the computational grid.

IV. RESULTS

Effects of baffles on the performance of WSP

The summary of effluent concentrations and removal efficiency of BOD concentrations for different cases of baffles are presented below. The results for the studied three cases were concluded as follows:

For case 1, without baffles the effluent BOD concentration was found in the range of (235 - 252) mg/l for laboratory study while CFD model gave a range of (242 - 258) mg/l. The effluent concentration of DO ranged between (0.26 – 0.50) mg/l and velocity ranged between (2.4 x 10^{-6} – 2.8 x 10^{-3}) m/sec at the same conditions.

For case 2, with two baffles, the effluent BOD concentration was found in the range of (22.0 – 233) mg/l while CFD prediction gave a range of (29 - 241) mg/l. The effluent concentration of DO ranged between (6.0 – 9.9) mg/l and velocity ranged between (9 x 10^{-5} – 0.16) m/sec at the same conditions.

For case 3, with four baffles, the effluent BOD concentration was found in the range of (12.0 – 55.0) mg/l, CFD model gave a range of (15 - 62) mg/l. The effluent concentration of DO ranged between (9.5 – 10.0) mg/l and velocity ranged between (4.7 x 10^{-5} – 0.76) m/sec at the same conditions.

The results showed that the case of four baffles (case 3) was an active case. The figure presented the results for the same cases to demonstrate the relationship between the effluent concentrations of BOD, at different cases of baffles.

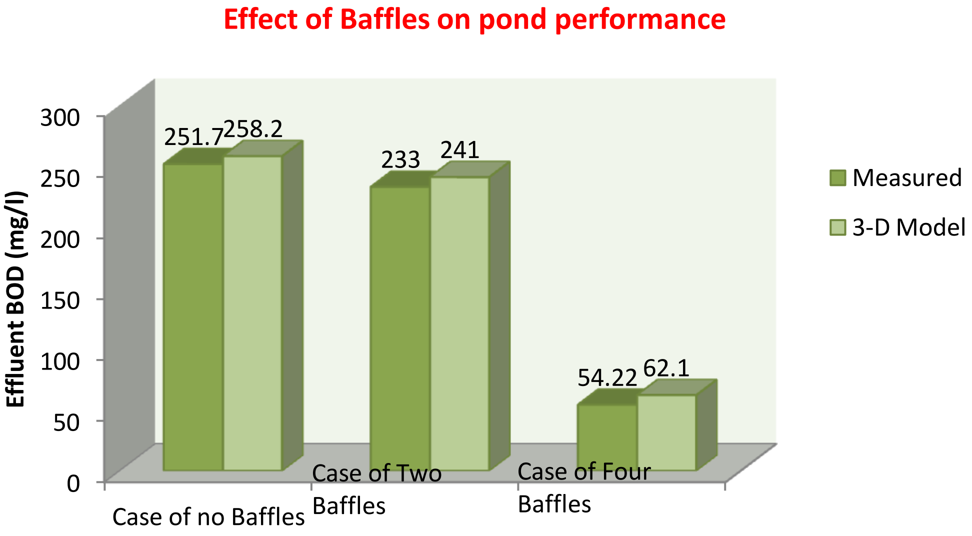

Fig.4.1: Effect of baffles on pond performance

The study has demonstrated that the BOD removal efficiency increased from 16% to 22% in case 1, from 22% to 92% in case 2 and from 82% to 96% in case 3. The DO effluent concentration decreased from 0.5mg/l to 0.26mg/l in case 1, increased from 6mg/l to 9.9mg/l in case 2 and increased from 9.5mg/l to 10.0mg/l in case 3.

Model Performance

The performance of the model developed in this study was assessed using various standard statistical performance evaluation criteria. The statistical measures considered were standard error of estimate (SEE), coefficient of correlation (CORR), mean absolute percentage error (MAPE), and root mean square error (RMSE). The MAPE measured the absolute error as a percentage of the forecast, and RMSE evaluated the residual between observed and predicted BOD concentration. CORR evaluated the linear correlation between the observed and predicted BOD concentration within the pond. At the end of the evaluation, the results were presented in Table 4.1 below.

Table 4.1: Performance of the model at different conditions of baffle(s)

	Conditions					
	With Four Baffles			Without Baffle		
Depth(m)	CORR	MAPE	RMSE	**CORR**	**MAPE**	**RMSE**
0	0.95	2.15	7.49	**0.94**	**2.34**	**8.00**
0.05	0.94	1.34	3.12	**0.92**	**2.15**	**3.55**
0.10	0.96	1.15	2.65	**0.96**	**1.73**	**5.02**
0.20	**0.93**	**2.56**	**4.11**	**0.91**	**3.78**	**5.51**

From the result, at the surface of the pond, the model performance with four baffles in terms of CORR, MAPE and RMSE were 0.95, 2.15 and 7.49, respectively, which were better than those obtained without baffle (0.94, 2.34 and 8.00 respectively). The same result applied to the remaining depths (0.05, 0.10 and 0.20), the reason being that the presence of baffles improved WSP performance and this was aptly accounted for by the model.

V. CONCLUSION

Modeling of waste stabilization pond was somewhat a daunting course due to the complexity involved in understanding its hydraulics. The results obtained were encouraging. The prediction of pond performance with measured values showed that an accuracy of 94% was obtained using the 3-D CFD model, an ultimate result that showed that the actual dispersion in the pond was three-dimensional. The 3-D model was used in series of investigation studies of the effects of baffles on pond performance using laboratory-scale pond data and comparison with tracer studies. In all, the results were satisfactory. The CFD model used in this study, demonstrates effectiveness and accuracy in describing the hydrodynamics of a large WSP, but at a high computational cost. Tracer experiments in large pond systems were costly in terms of time and resources, but are still very valuable to understand the system hydrodynamics. Incorporation of external factors like wind and thermodynamic stratification can certainly improve the CFD model but the computational demand will increase considerably.

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