Study of Convert Waste Stabilization Pond Geometry to Treated Wastewater Efficiency, (El-Burullus Lake, Egypt) As a Case Study

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***Abstract*— The simulation of hydrodynamics water quality in ponds is a developing tool that worth studying in order to understand their internal processes and interactions. Pond design involves several physical, hydrological, geometrical, biological and dynamic variables to provide high hydrodynamic efficiency and maximum substrate utilization rates. Computational fluid dynamic modelling (CFD) allows the combination of these factors to predict the behavior of ponds by using different configurations. In this research mathematical model developed by Danish Hydraulic Institute (DHI), was formulated to simulate WQ parameter. This model was calibrated and used to simulate a scenario to improve study reach water quality in polluted lakes. The study applied on El-Burullus Lake, which is the second largest northern lake in Egypt which belongs to high eutrophic lake type and suffers from several problems. The model was run at steady and variable state with raw wastewater to study the real effect of the polluted drains, which discharge high amount of polluted wastewater into the El-Burullus Lake and know the lake situation after make baffles scenario. The major functions performed by baffles are to reduce hydraulic short-circuiting and to provide a submerged surface which can encourage the growth of attached biomass. Attached biomass growing on the surface of the baffles could increase the total mass of organisms in the pond and thus improve the treatment efficiency and therefore reduce the eutrophication rate in the pond such as (NH_3-N, PO_4-P & NO_3-N). Results showed that there are a significant variance between the rate of NH_3-N, PO_4-P & NO_3-N before and after make baffles, and the overlap between baffles (L=0.50 baffle) is more efficient than no overlap. In conclusion, waste ponds and be improved easily and economically to be more efficient by making baffles in the lake which can increase the water velocity, avoided the dead zones area and reduce the eutrophic concentration.**

***Keywords*— Pond, Hydrological, Geometrical, Computational fluid dynamic, Modelling, Wastewater treatment, Baffles.**

I. INTRODUCTION

There are many methods of wastewater treatment; undoubtedly, the stabilization pond is one of the most common wastewater treatment techniques, especially if low cost land is available or there is a waste lake need a rehabilitation. In modern societies, environmental management programs use models of systems that will examine and evaluate the possible alternatives. The mathematical models are commonly used in the areas of the fluid dynamic, surface water hydrology, the subsurface water hydrology and water quality processes and flow velocities in lakes. Numerical models or mathematical simulation models are currently widely used in the field of water quality management (to predict the concentrations of dissolved oxygen, eutrophication rate, toxic & etc.) and in the field of hydrodynamics.[1]

Several techniques are used to treat domestic wastewater. These can be classified into two groups: conventional and non-conventional treatment plants. The former has high-energy requirements. The later is solely dependent on natural purification processes. The conventional systems of wastewater treatment includes trickling filters, activated sludge systems, biodisc rotators and aerated lagoons. The non-conventional systems, which are also called eco-technologies include constructed wetlands (CW) and waste stabilization ponds (WSPs). Among these technologies, the widely recommended ones for developing countries are the WSPs. Waste stabilization ponds are biological treatment systems, which processes and operations are highly dependent on the environmental conditions such as temperature, wind speeds and light intensity which highly variable and any given combination of these environmental parameters.[2]

In this research study, Burullus Lake in Egypt has been chosen to apply the baffle scenario, this lake is the second largest delta lake in Egypt, which receives a total drainage discharge of 4 billion m3/y. The lake is a consistent water body for fulfilling the needs of domestic, agricultural and industrial activities. [3] Recently, Burullus Lake has become a dumping site for huge amounts of agricultural runoff coming from sectors/lands of the Delta region. Based on flow mass balance of the lake, discharges from agricultural activities are responsible for more than 90% of the total inflows into the lake. Additionally, the lake receives wastewater coming from urban sewage and industrial facilities. Currently, the lake is facing many challenges, such as eutrophication, high load of contamination, reduction of the area, and depletion of fish production. As a result, Burullus Lake has become unfit for fishing, agricultural and other domestic purposes. [4]

The study aimed at:

a) Study the real effect of the baffles on the water velocity and dissolved oxygen in the pond area.

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b) Know the efficiency of the overlap between two baffles on the water circulation, to avoid the dead zones area in the lake.
c) Applying the baffles scenario on El-Burullus lake as a case study to know the possibility of improve water quality by reducing the rate of eutrophic parameters (NH_3-N, NO_3-N, PO_4-P) rate and BOD level.

II. MATERIALS AND METHODS

A. WSPs systems

(WSPs) and (CW) are increasingly applied for domestic wastewater treatment as they can offer completely natural purifying processes. WSP and CW designers come from many different backgrounds or disciplines, including civil engineering, environmental engineering, microbiology, chemical engineering, soil science, or natural resources management. There are several types of (WSPs), Anaerobic, facultative , aerobic (maturation) ponds.

Anaerobic ponds are built to a depth of 2 to 5 m and have a relatively short detention time of 1 to 7 days. Facultative ponds should be constructed to a depth of 1 to 2.5 m and have a detention time between 5 to 30 days. Aerobic ponds are usually between 0.5 to 1.5 m deep with a detention time of 15 to 20 days. If used in combination with algae and/or fish harvesting, this type of pond is effective at removing the majority of nitrogen and phosphorus from the effluent. [5]

B. Effects of baffles on WSPs performance

For the purposes of this research study, a baffle will be considered as any physical restriction, which directs the flow of wastewater through a pond.

The major functions performed by baffles are to reduce hydraulic short-circuiting and to provide a submerged surface, which can encourage the growth of the attached biomass. Attached biomass growing on the surface of the baffles could increase the total mass of organisms in the pond and thus improve the treatment efficiency and therefore reduce the eutrophication rate in the pond. In addition to the Hydraulic, short-circuiting could be reduced because the flow of the wastewater through the pond would follow a path determined by the configuration of the baffles, depending upon the baffle configuration. Hydraulic turbulence could be promoted which would encourage mixing of the liquid and maintain the velocity of the wastewater. [6]

Most of the literature pertaining to the effects of baffles on the performance of waste stabilization ponds is vague. Several investigators have used baffles in waste stabilization ponds and indicated that the performance of the pond was affected to the better side.[7]

C. Dynamic equations and modelling

The following governing equations are used to solve the depth integrated equations of fluid mass and momentum conservation in two horizontal directions. The forms of the solved equations are:

$$h\frac{du}{dt}+hu\frac{du}{dx}hv\frac{du}{dy}-\frac{h}{\rho}\left(E_{xx}\frac{d^2u}{dx^2}+E_{xy}\frac{d^2u}{dy^2}\right)+gh\left(\frac{da}{dx}+\frac{dh}{dx}\right)+\frac{gun^2}{(1.486h^{\frac{1}{6}})^2}+(u^2+v^2)^{\frac{1}{2}}-\xi Va^2\cos\psi-2h\omega v\sin\phi=0 \quad (1)$$

$$h\frac{dv}{dt}+hu\frac{du}{dx}hv\frac{du}{dy}-\frac{h}{\rho}\left(E_{yx}\frac{d^2v}{dx^2}+E_{yy}\frac{d^2v}{dy^2}\right)+gh\left(\frac{da}{dy}+\frac{dh}{dy}\right)+\frac{gvn^2}{\left(1.486h^{\frac{1}{6}}\right)^2}+(u^2+v^2)^{\frac{1}{2}}-\xi Va^2\sin\psi-2h\omega v\sin\phi=0 \quad (2)$$

$$\frac{dh}{dt}+h\left(\frac{du}{dx}+\frac{dv}{dy}\right)+u\frac{dh}{dx}+v\frac{dh}{dy}=0 \quad (3)$$

where h is the water depth, u and v are the velocities in the Cartesian directions, *x*, *y* and *t* are the Cartesian coordinates and time, ρ the density of fluid, E the eddy viscosity coefficient (for *xx* is the normal direction on x-axis surface; for *yy* is the normal direction on y-axis surface; for *xy* and *yx* are the shear direction on each surface), *g* the acceleration due to gravity, a the elevation of bottom, *n* the Manning's roughness n-value, 1.486 the conversion from SI (metric) to non-SI units, ξ the empirical wind shear coefficient, V*a* the wind speed, ψ the wind direction, ω the rate of earth's angular rotation and ϕ is the local latitude.

Equation (1) & (3) are solved by the finite element method using the Galerkin method of weighted residuals. The solution is fully implicit and the set of simultaneous equations is solved by Newton–Raphson nonlinear iteration. The computer code executes the solution by means of a front-type solver, which assembles a portion of the matrix and solves it before assembling the next portion of the matrix. For determination of water quality parameters, the following governing equation solves the depth-integrated equations of the transport and mixing process.

The form of the depth averaged transport equation is:

$$h\left(\frac{dc}{dt}+u\frac{dc}{dx}+v\frac{dc}{dy}-\frac{d}{dx}D_x\frac{dc}{dx}-\frac{d}{dy}D_y\frac{dc}{dy}-\sigma+\kappa c+\frac{R(c)}{h}\right)=0 \quad (4)$$

where h is the water depth, c the concentration of pollutant for a given constituent, t the time, u and v are the velocity in x direction and y-direction, *Dx* and *Dy* are the turbulent mixing (dispersion) coefficient, k is the first order decay of pollutant, the source/sink of constituent and *R(c)* the rainfall/evaporation rate. The equation is solved by the finite element method using Galerkin weighted residuals. Spatial integration of the equations is performed by Gaussian techniques. The model, which was selected for the present study, is surface-water modelling system (Mike 21) Mike is a comprehensive environment for two-dimensional hydrodynamic & ecological modelling.

D. Boundary conditions

The model was run at steady-state case with raw wastewater to study the effect of the baffles with constant area, depth, flow rate and hydraulic retention time on the stabilization ponds performance. The model was run with different temperature and three cases of baffle scenario as shown in figure 1. The operated boundary conditions for the present study were chosen as follows:

- Flow rate inlet is constant (100 m^3/hr).
- Constant depth (1.5 m).
- Optional boundary conditions (isotropic eddy viscosities, diffusion coefficients, Manning's n-values and dispersion coefficients) were also calculated.

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- Eutrophic water characteristics were assumed to be as the case study of El-Burullus lake: (influent concentration of DO =3.12mg/l, NH_3-N=5.2mg/l, NO_3-N=1.5 mg/l, PO_4-P=1.5mg/l & BOD=11.8mg/l.
- Hydraulic retention time 5 days.

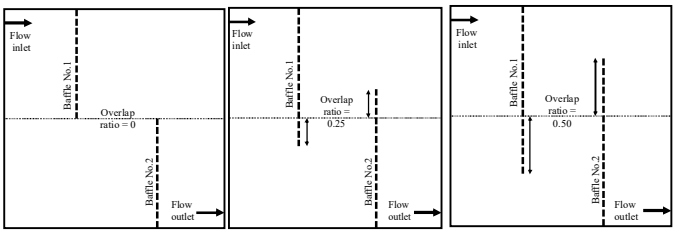


Fig.1 The baffles situation scenario in the boundary

III. RESULTS AND DISCUSSION

After finished the model scenario of the baffles in the boundary, the results show increasing in the water velocity compared to the same without baffles. There is a significant variance at the eutrophic concentration (NH_3-N, NO_3-N and PO_4-P) between the influent wastewater inlet and outlet. The summary of effluent concentrations and removal efficiency of NH_3-N, NO_3-N, PO_4-P and BOD concentrations and velocities values, for different cases of baffles are given in Table 1.

Table I: The Summary Of The Eutrophic Effluent And Removal, DO Effluent And Velocities At Different Temperature With Different Baffles Scenario.

Avarage flow rate input 100 m^3/hr	Water Temperature															
	20° C				25° C				30° C				35° C			
	Case of no baffles															
	Min	Max	Mean	Percent of removal %	Min	Max	Mean	Percent of removal %	Min	Max	Mean	Percent of removal %	Min	Max	Mean	Percent of removal %
DO (influent concentrations 3.12 mg/l)	3.120	3.938	3.457		3.120	4.224	3.646		3.070	3.630	3.272		2.670	3.170	2.998	
NH_3-N (inf.con 5.2 mg/l)	4.340	5.200	4.722	21.9	4.265	5.200	4.710	22.4	3.760	5.200	4.193	18.3	2.850	5.200	3.675	25.6
NO_3-N (inf.con 1.5 mg/l)	1.355	1.500	1.385	8.7	1.287	1.500	1.342	11.2	1.122	1.500	1.220	25.2	1.003	1.500	1.138	31
PO_4-P (inf.con 1.5 mg/l)	1.370	1.500	1.443	4.0	1.296	1.500	1.385	3.0	1.223	1.500	1.342	8.3	1.054	1.500	1.193	21.7
BOD (inf.con 11.8 mg/l)	11.532	11.800	11.643	2.2	11.517	11.800	11.629	5.7	10.443	11.800	10.736	11.5	9.432	11.800	9.956	19.1
velocity m/sec	0.1260	1.2000	0.4962		0.1430	1.2000	0.5178		0.1520	1.2000	0.5327		0.172	1.200	0.605	
Case of one baffle																
DO	3.1200	4.2241	3.6462		3.1200	3.9850	3.5242		3.0700	3.6300	3.2717		2.650	3.450	2.998	
NH_3-N	4.2650	5.2000	4.7100	21.6	3.8800	5.2000	4.3500	23.1	3.5960	5.2000	4.0667	21.2	2.696	5.200	3.547	28.5
NO_3-N	1.2870	1.5000	1.3421	14.2	1.2330	1.5000	1.2981	16.9	1.0360	1.5000	1.1765	30.9	0.948	1.500	1.095	26.7
PO_4-P	1.2960	1.5000	1.3850	9.6	1.1870	1.5000	1.3335	9.2	1.1465	1.5000	1.2783	13.4	0.999	1.500	1.142	26
BOD	11.517	11.800	11.629	2.3	11.109	11.800	11.371	5.9	10.268	11.800	10.604	13.0	9.157	11.800	9.349	21.4
velocity m/sec	0.0023	1.2000	0.4713		0.0043	1.2000	0.5320		0.0045	1.2000	0.5459		0.007	1.200	0.601	
Case of two baffles (no overlap between baffle)																
DO	3.1200	4.4784	3.8024		3.1200	4.1680	3.6600		3.1200	3.8060	3.4183		2.760	3.570	3.140	
NH_3-N	4.1820	5.2000	4.6408	22.0	3.7070	5.2000	4.2058	20.3	3.4290	5.2000	3.9258	24.1	2.507	5.200	3.389	32.2
NO_3-N	1.1780	1.5000	1.2570	17.9	1.1780	1.5000	1.2570	20.6	0.9320	1.5000	1.1084	37.9	0.845	1.500	1.025	43.7
PO_4-P	1.2530	1.5000	1.3492	12.5	1.1030	1.5000	1.2635	14.8	1.0265	1.5000	1.1783	21.4	0.899	1.500	1.049	34.5
BOD	11.353	11.800	11.504	3.8	10.821	11.800	11.208	8.3	9.903	11.800	10.344	16.1	8.624	11.800	9.345	25.9
velocity m/sec	0.3070	1.2000	0.6453		0.3270	1.2000	0.7323		0.3270	1.2000	0.7475		0.339	1.200	0.821	
Case of Two baffles (overlap between baffle ratio 0.25)																
DO	3.1200	4.8638	4.0861		3.1200	4.6980	4.1072		3.1200	3.8614	3.4728		2.750	3.620	3.180	
NH_3-N	4.0280	5.2000	4.5125	22.8	3.4200	5.2000	3.9667	25.8	3.1860	5.2000	3.7183	28.7	2.262	5.200	3.185	36.9
NO_3-N	1.1770	1.5000	1.2503	21.5	1.1120	1.5000	1.2027	25.6	0.7680	1.5000	1.0046	48.8	0.651	1.500	0.905	56.6
PO_4-P	1.1580	1.5000	1.2792	20.5	0.9710	1.5000	1.1535	23.6	0.8505	1.5000	1.0316	33.2	0.765	1.500	0.929	45.4
BOD	11.113	11.800	11.330	5.8	10.367	11.800	10.963	12.1	9.337	11.800	9.967	20.9	7.992	11.800	8.901	31.3
velocity m/sec	0.5110	1.2000	0.8087		0.5310	1.2430	0.8957		0.5310	1.3030	0.9108		0.543	1.311	0.984	
Case of Two baffles (overlap between baffle ratio 0.50)																
DO	3.1200	5.0203	4.2340		3.1200	4.8210	4.2097		3.1200	3.9044	3.5087		2.870	3.730	3.287	
NH_3-N	3.7630	5.3000	4.3083	24.2	3.1330	5.3000	3.7442	32.6	2.9320	5.3000	3.5367	34.1	1.950	5.300	2.942	44
NO_3-N	1.1054	1.5000	1.1892	25.8	1.0287	1.5000	1.1428	30.7	0.5800	1.5000	0.8973	61.3	0.396	1.500	0.745	73.6
PO_4-P	1.0130	1.5000	1.1475	32.5	0.7860	1.5000	0.9993	35.9	0.6737	1.5000	0.8843	45.0	0.621	1.500	0.799	57.7
BOD	10.810	11.800	11.089	8.4	9.902	11.800	10.650	16.1	8.705	11.800	9.588	26.2	7.258	11.800	8.390	37.5
velocity m/sec	0.5840	1.2000	0.8695		0.6040	1.3160	0.9565		0.6040	1.3760	0.9717		0.616	1.384	1.045	

The results for the studied five cases are concluded as follows:

Case 1: without baffle. The velocity ranged between 0.126 and 0.172m/s, which the lowest valves on the sides of boundary and increases gradually in the middle. The minimum valves of the DO was at temp 35^0c 2.67mg/l, and a simple reduction at the values of NH_3-N, NO_3-N, PO_4-P and BOD from (4.34, 1.355,1,37, 11.532) mg/l to (3.85, 1.25, 1.054,10.12)mg/l respectively.

Case 2, 3, 4&5: as shown in figure 2(a). The velocity at one baffle scenario ranged between 0.172m/s and 0.0023m/s, leading a dead zone area. Conversely, the velocity increased to be (0.61, 0.821, 0.984 &1.045) m/s respectively at the other three cases. Figure 2(b) show a good variation at NH_3-N, which decreased from 3.547 to 2.942 mg/l. the values show that the wastewater characteristics has been improved, because high rate of the un-ionized component of NH_3-N can be toxic to the aquatic life.

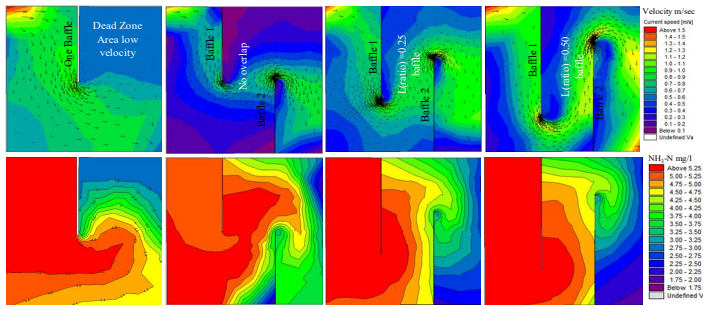


Fig.2 WSP simulations plots (a) velocity distribution (b) NH_3-N concentration

After applying this study on the El-Burullus lake the results show at figure 3 an increasing in velocity values from 0.001m/s to 0.008m/s and the percentage of NH_3-N reduced from 5.03mg/l to 0.474mg/l. The results show significant improvement in the water quality of the lake and began to turn into Oligotrophic type, As a result, biological activity will be generally low, the water is clear, and the water column is often well supplied with oxygen throughout the year.

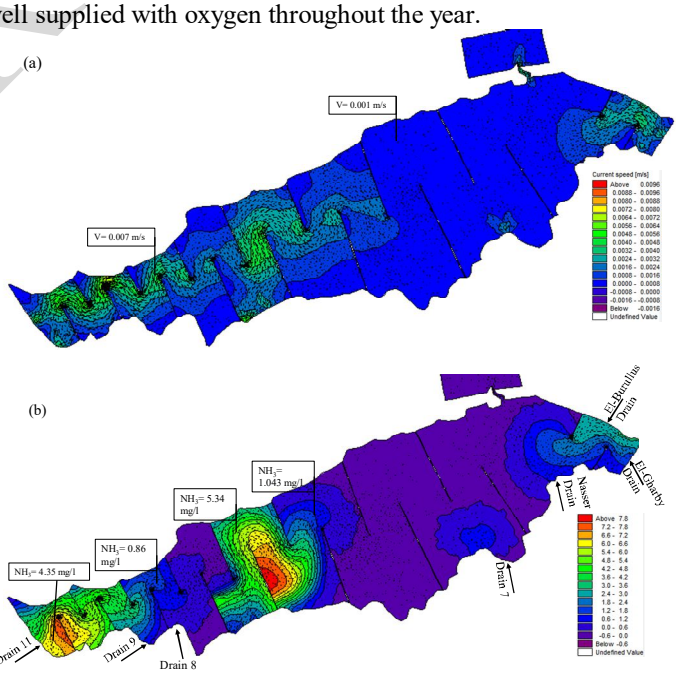


Fig.3 Scenario Output after Applying Baffles In (El-Burullus Lake) (a) The Velocity (m/sec) (b) NH_3-N (mg/l)

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IV. CONCLUSION

The results obtained through the present study showed that the increasing the length of the water path by applying baffle scenario in the pond increase in the removal efficiency of NH_3-N, NO_3-N, PO_4-P and BOD concentrations.

The overlap ratio between baffles is more efficient than no overlap, which leads to making a homogeneity in water body and reduce the dead zones area in the lake and therefore improve water quality in the lake and the economic benefits from the lake be better in the future.

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