CSCanada
Energy Science and Technology
Vol. 5, No. 2, 2013, pp. 31-35
DOI:10.3968/j.est.1923847920130502.2512

ISSN 1923-8460[PRINT]
ISSN 1923-8479[ONLINE]
www.cscanada.net
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Empirical Regression Model for Biochemical Oxygen Demand Removal in Solar Enhanced Waste Stabilization Ponds

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Received 30 March 2013; accepted 02 May 2013

Utsev, J.T., Ogarekpe, N.M., Tivde, T. (2013). Empirical Regression Model for Biochemical Oxygen Demand Removal in Solar Enhanced Waste Stabilization Ponds. *Energy Science and Technology, 5*(2), 31-35. Available from: http://www.cscanada.net/index.php/est/article/view/j.est.1923847920130502.2512. DOI: http://dx.doi.org/10.3968/j.est.1923847920130502.2512.

Abstract

Consequent on the findings that a Solar Enhanced Waste Stabilization Pond (SEWSP) will increase treatment efficiency thereby reduce the large land area requirement; hence, this study aims at developing an empirical regression model for the prediction of the efficiency of Biochemical Oxygen Demand removal of the SEWSPs for sewage treatment. SEWSPs were constructed of varying sizes made of metallic tank with inlet and outlet valves, and a solar reflector to increase the incident sunlight intensity. Physio-chemical and biological characteristics of the wastewater samples were collected from different points (inlet and outlets) of the SEWSPs were examined for a period of two months. The examined parameters were: Efficiency of BOD removal in %, Efficiency of E Coli removal in %, Dissolve Oxygen in mg/l, Efficiency of COD removal in %, Efficiency of Suspended Solid removal in %, Temperature in^0**C**, Detention Time in days and coliform. Discussions were made revealing the relationship between the depth of the SEWSP and treatment efficiency.An empirical correlation model predicting the efficiency of BOD removal for the SEWSP was developed thus $y = - 0.292X_1 – 0.1011X_2 + 0.876X_3 + 0.148X_4 – 0.087X_5 +0.012X_6 + 22.939$ together with a MATLAB solver for easy computation.

Key words: Waste Stabilization Pond; Solar Enhanced; Prediction; BOD; Model

INTRODUCTION

A solar enhanced Waste Stabilization Ponds (SEWSPs) is a new technology that evolved as a result of the incorporation of solar reflectors in the conventional waste stabilization pond for the purpose of increasing the efficiency and reducing the land area requirement of the waste stabilization pond (Agunwamba*et al*., 2009). Waste Stabilization Ponds (WSPs) are popular wastewater treatment system used for the removal of organics and pathogenic organisms. It consists of a large, shallow earthen basin in which wastewater is retained long enough for natural purification processes to provide the necessary degree of treatment (Agunwamba, and Ogarekpe, 2010). High efficiencies of WSP have been reported with respect to removal of intestinal nematode (Lakshmarayana and Abelulapa, 1972; Feachem et al., 1983; Saqqar and Pescode, 1992); organic compounds and faecal bacteria (Mara, 1976). In addition, it is also economical (Arthur, 1983). It is simple to construct, operate and maintain and it does not require any external energy input.

However, the main constraint against selecting this technology is not land cost but land availability. WSPs are limited in application by their large area requirement (Mara et. al., 1983). In the past, researches have been conducted to improve pond efficiency, thereby maximizing land use by solar enhanced wastewater treatment in waste stabilization ponds (Agunwamba et al., 2009), using hydraulic jump (Agunwamba and Ogarekpe, 2010), using optimization techniques (Agunwamba and Tanko, 2005), using recirculation stabilization ponds in series (Shelef et al, 1978), step feeding (Shelef et al., 1978), incorporating an attached growth system (Shin and Polpraset, 1987) and more accurate estimation of pond design parameters (Agunwamba, 1992; Marecos do Monte and Mara, 1987; Mayo, 1989; Polpraset et al., 1983; Sarikaya and Saatci, 1987; Sarikaya et al., 1987; Sweeney et al., 2007). In addition, higher pond depths have been investigated for reduction of the pond surface area (Hosetti and Patil, 1987; Oragui et al., 1987; Pearson et al., 2005; Silver et al., 1987). Agunwamba (2001) investigated the effect of tapering on WSP performance. Research has revealed that the cost of treating wastewater using SEWSPs was about 77.6% lower than the conventional WSP for the same treatment efficiencies (Agunwamba et al., 2009).

The lower cost implication of treating wastewater using the SEWSP has perhaps widened the applicability and popularity making it more affordable for use in urban communities.

To this end the specific objective of this research is to develop an empirical regression model for the prediction of the efficiency of BOD removal in SEWSPs.

1. EXPERIMENTAL SET UP

Located at the north-eastern end of the University campus about 800m from the junior staff quarters, the treatment plant at Nsukka consists of a screen (6mm bar racks set at 12 mm centres) followed by two Imhoff tanks, each measuring about 6.667 m x 4.667 m x 10m, and two facultative waste stabilization ponds. Sludge is discarded from the Imhoff tank once every ten days onto one of the four drying beds, so that the beds are loaded at 40 days interval. The beds have a total area of 417 m^2. Although its efficiency has deteriorated, its effluent is used for uncontrolled vegetable irrigation by some village dwellers. The poor effluent quality is also partly attributable to overloading because of population growth. Three (3) out of the four ponds were constructed with a tilt frame at 45^0 for fixing the solar reflectors each of size 0.4 m by 1.0m. All the ponds were operated at a detention time of 3 days. The detailed descriptions of the various ponds are explained in the table 1.

The four solar ponds were filled with sewage from the second facultative pond through a sewage storage tank. Storage tanks were fed continuously by an overhead storage tank which in turn was filled with sewage from a facultative pond through an underground pipe, with the aid of a water pump being powered by a generator. The schematic diagram of the experimental setup is shown in Figure 1, while the pictorial diagram of the setup is presented in (Agunwamba et al, 2009).

1.1 Sampling

In the determination of BOD, COD, suspended solids, E-coli and total coliform concentrations, five samples were collected from the four different solar ponds and one from the outlet of the storage tank were taken for laboratory analysis. Ponds of different depths were chosen in order to analyse the effect of depth on the efficiency of solar enhanced treatment in WSP which were monitored for a period of two months.

Table 1
Detailed Description of the Various Ponds

Experimental Ponds	Size (m)	Characteristics	Purpose
A	1 x 0.4 x 0.4	No solar reflector	Control
B	1 x 0.4 x 0.4	Solar reflector	Measure the effect of solar reflector
C	1 x 0.4 x 0.2	Solar reflector	Measure the effect of depth
D	1 x 0.4 x 0.6	Solar reflector	Measure the effect of solar reflector

1.2 Physical Pond Design

The physical pond design followed Agunwamba*et el* (2009). The study was conducted using a 1:20 scale model of a conceptualized prototype waste stabilization pond. Geometrical similarity was applied for the design of the scale model pond. The design was performed first using Froude number similarity and compared with Reynold's number. The conceptualized prototype pond was characterized by an unusual depth (8.0m) and was chosen for the studies to simplify experimental measurements. The ratios that must exist between the model and prototype pond as well as the corresponding flow characteristics are given in Table 2.

Table 2
Prototype to Model Relationships on Kinematics Similarity (Reynolds Model) Law

Parameter	Unit	Equation	Relationship	Prototype	Model
Length, L	M	α	1/20	20	1
Width, W	M	α	1/20	8	0.4
Depth, D	M	α	1/20	8	0.4
Surface Area, A	M^2	α^2	1/400	160	0.4
Volume, V	M^3	α^3	1/8000	1280	0.16
Ideal detention time, T (=V/Q)	hrs	α^2	1/400	160	0.4
Influent rate, Q	M^3/d	α	1/20	264	13.2
Average theoretical Velocity (U=QD/V)					
Average Pond Reynold's No. Re (Re=UR_h/ע)	M/d	α^{-1}	20	4.125×10^{-2}	8.25×10^{-1}
Average Froude No.					
Fr=$u/(gR_h)^{0.5}$	_	α^0	1	116	116
	_	α^{-2}	40	1.54×10^{-5}	6.21×10^{-4}

Table 3
Average Removal Efficiencies of the Ponds with Respect to all the Parameters Investigated (Agunwamba et al., 2009)

Pond	Parameters					
	Coliform	E.Coli	BOD$_5$	COD	SS	DO
A	52±12.4	41.7±17.3	23.5±6.1	25.7±5.9	19.5±9.8	7.7±1.4
B	82.0±10.2	63.6±14.9	48.2±10.0	45.9±13.1	48.4±8.9	7.1±1.2
C	85.1±18.1	74.3±13.3	52.7±5.7	54.4±4.7	56.8±12.8	6.0±1.4
D	74.6±11.4	47.8±20.9	30.4±7.6	32.2±8.9	25.3±11.7	7.1±1.9

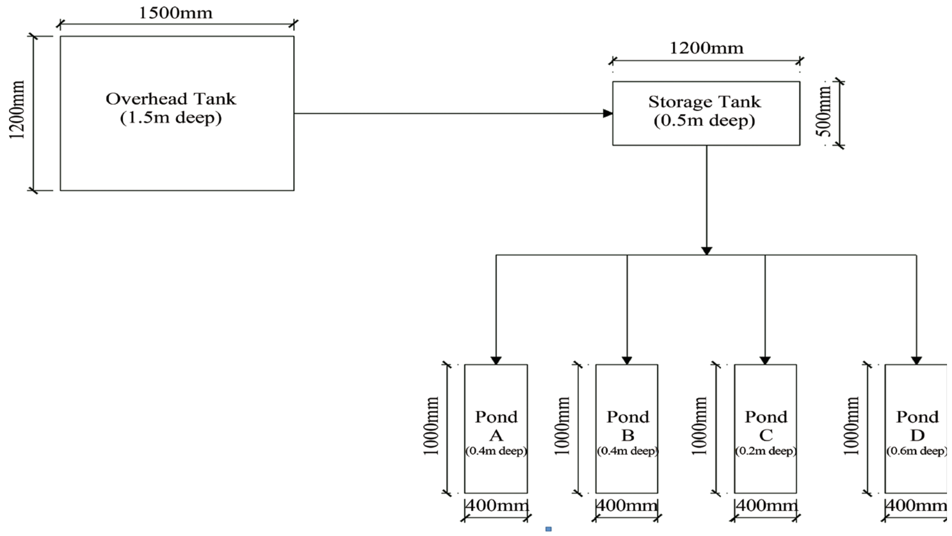

Figure 1
Schematic diagram of experimental setup
a: Samples in two replicates and n = 20.

1.3 Methods of Analysis

All sewage samples collected for laboratory analysis were analyzedbased on the standard methods (APHA et al., 1992). The results of the data obtained for the pond with two steps were subjected to multiple regression analysis.

2. RESULTS AND DISCUSSIONS

Figure 2 below depict the variations of efficiencies of BOD removal of the SEWSPs with respect to solar radiation. The trend in the graphs has shown that, the efficiency of BOD removal increases with increase in solar radiation across the ponds. It is also observed that Pond C has the highest Efficiency of BOD removal followed successively by Pond B, Pond D and Pond A respectively. This is because of the variation in the depths of the Ponds, where Pond C has the least depth of 0.20m followed in the same scenario as described before.

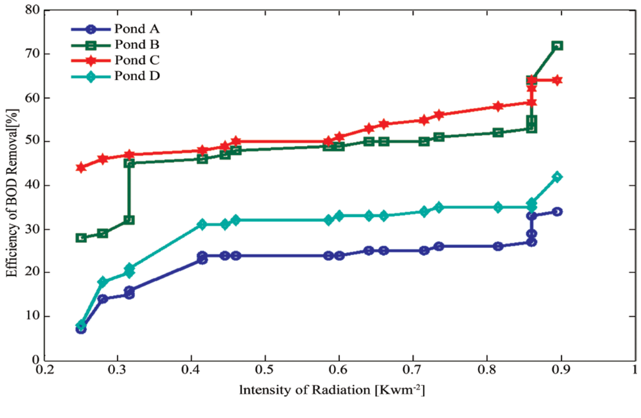

Figure 2
Efficiency of BOD Removal Versus Solar Intensity (Agunwamba et al., 2009)

2.1 Determination of Regression Model

Applying regression statistics on the results obtained from the laboratory analysis of pond C being the pond with the highest efficiency of BOD removal, it is observed that a linear correlation exists between the data with the following parameters:

Coefficient of determination, r = 0.557
Standard error, s = 4.917
Degree of freedom, $d_f = 12$

The equation below is obtained as an empirical regression model for the prediction of the efficiency of biochemical oxygen demand removal in solar enhanced waste stabilization pond.

$$y = -0.292X_1 - 0.1011X_2 + 0.876X_3 + 0.148X_4 - 0.087X_5 + 0.012X_6 + 22.939 \quad (1)$$

where

Y = Efficiency of BOD removal in %
X_1 = Efficiency of E Coli removal in %
X_2 = Dissolve Oxygen in mg/l
X_3 = Efficiency of COD removal in %
X_4 = Efficiency of Suspended Solid removal in %
X_5 = Temperature in ^{0}**C**
X_6 = Detention Time in days

The correlation of 0.557and standard error of 4.917may not be too significant due to the non-consideration of the other parameters such as solar altitude angle, solar azimuth angleetc that affect the performance of waste stabilization ponds. In essence, we have computed the correlation coefficients using SPSS which returned the result that the correlation is significant at both 0.05 and 0.01 significant levels for a two tailed test. Our observations from the returned correlation values show that the minimum correlation value returned is 0.808.

This model is of much practical importance in the determination of BOD removal for SEWSP. With the aid of the model, the selected parameters for the construction of the pond becomes very abrupt and simple since there is that opportunity of imputing the required parameters as we have stated in Equation (1). It is now very important to recall that the SEWSP designer must have a targeted BOD output, therefore, the predicted BOD removal is achieved whenever the required parameters are imputed to easy the design.

2.2 MATLAB CODE Computation of BOD Removal

We have developed here a simple MATLAB Solver that can aid in the computation of BOD removal across a particular pond at a time. The MATLAB Solver simply requests the user to input: X1, X2, …, X6 and press the ‘enter’ key and a value of ‘Y’ is returned. This code is presented below:

```
% Programme to compute the Efficiency of BOD removal in %
% Dr. J.T. Utsev, N.M. Ogarekpe and T. Tivde
% Coliform = X1
%X1 = [52 82.0 85.1 74.6];
X1 = input(‘Coliform, X1 =’)
%E_Coli = X2
%X2 = [41.7 63.6 74.3 47.8];
X2 = input(‘E_Coli, X2 =’)
% BOD5 = X3
%X3=[23.5 48.2 52.7 30.4];
X3 = input(‘BOD5, X3 =’)
% COD = X4
%X4 = [25.7 45.9 54.4 32.2];
X4 = input(‘COD, X4 =’)
% SS = X5
%X5 =[19.5 48.4 56.8 25.3];
X5 = input(‘ SS, X5 =’)
% DO = X6
%X6 = [7.7 7.1 6.0 7.1];
X6 = input(‘DO, X6 =’)
Y = -0.292*X1 - 0.1011*X2 + 0.876*X3 + 0.148*X4-0.087*X5 +0.012*X6 + 22.939
```

CONCLUSION

Sewage effluent from the University of Nigeria, Nsukka was studied in a solar enhanced waste stabilization pond model. Four ponds were studied. Three out of the four ponds constructed with metals were fitted with solar reflector (aluminum sheets) to increase the incident sunlight intensity. Laboratory analysis was carried out in order to examine some physio-chemical and biological parameters to ascertain an empirical regression model for the prediction of the efficiency of biochemical oxygen demand removal in solar enhanced waste stabilization ponds.

The empirical regression analysis of the results revealed that the equation obtained above is a regression model for the prediction of the efficiency of biochemical oxygen demand removal in solar enhanced waste stabilization ponds.

RECOMMENDATIONS

Based on the findings of this research, it is recommended that for a pond with length/width/depth ratio of 1.0: 0.4: 0.20, the aforementioned regression model can be used to optimize the design of solar enhanced waste stabilization ponds for the efficiency Biochemical Oxygen Demand removal for sewage treatment.

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