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MODELING OF DOMESTIC WASTEWATER TREATMENT FACULTATIVE STABILIZATION PONDS

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ABSTRACT

The processes of Biological treatment intend to reduce the organic matter content by using microorganisms. Problems, which often occur in the treatment process, include the Wastewater Treatment Plant (WWTP) being planned for treating domestic wastewater only, but in fact the WWTP often receives non-domestic wastewater particularly direct or indirect faecal deposits. There are 13 simultaneous systems of nonlinear differential equations using the method of Runge-Kutta-Fehlberg (RKF45). Data validation is measured in a facultative stabilization pond at a distance of 0 m, 25 m, 50 m and 75 m respectively. Samples are taken at the inlet and outlet of the pond covering the concentration of Bacteria (B), Algae (A), Zooplankton (Z), Organic Matter (OM), Detritus (D), Organic Nitrogen (ON), Ammonia (NH_3), Organic Phosphorus (OP), Soluble Phosphorus (SP), Dissolved Oxygen (DO), Total Coliform (TC), Faecal Coliform (FC), and Biochemical Oxygen Demand (BOD). The research comparing observation and count data results in 11 kinds of concentration that have a relative error <20% and 2 concentrations > 20%, namely Chemical Oxygen Demand (COD) and Faecal Coliform.(FC). Wastewater quality is predicted with 45^o angle charts and tolerance ± 20%, respectively for BOD (76.8%), COD (57.7%) and DO (81.9%). The model, as a means for performance evaluation of the WWTP, is appropriate for Class II water quality standards.

Keywords: Domestic waste water; Facultative Stabilization Pond; Performance evaluation; Waste Water Treatment Plant (WWTP)

1. INTRODUCTION

Facultative stabilization pond is a part of a stabilization pond system used for improving the quality of waste water. The prominent characteristic of urban waste water is its high organic content. Biological processes happen in it and its supporting physical phenomena are not widely understood, due to the complexity of environment factors (Rositayanti & Suprihantono, 2004). Therefore, ineffectiveness in the operation of facultative pond happens. One of the Waste Water Treatment Plants (WWTP) using the facultative stabilization pond system is Sewon Bantul WWTP. The process is done biologically, which is aimed at reducing the organic matter content by using microorganisms. The facultative stabilization pond is used to improve the quality of wastewater by relying on natural processes of wastewater treatment using the presence of

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bacteria, algae, and zooplankton to reduce organic pollutants contained in wastewater (Kayombo et al., 2002; Mashauri & Kayambo, 2002; Beran & Kargi, 2005; Lani et al., 2005; Naddafi et al, 2009; Amoo & Aremu, 2012).

Hydraulic characteristics are one of the factors promoting the optimal performance of the treatment unit. If the hydraulic conditions do not promote treatment, then the unit performance is unsatisfactory. Waste stabilization ponds are suitable for application in developing countries (particularly in tropical areas where the climate is warm). The operation of the pond requires neither high investment for operating costs nor special personnel, (Mashauri & Kayambo, 2002; Kayombo et al., 2003; Mara, 2004; Lani et al., 2005).

The basic principles of the stabilization pond are balancing and maintaining the organic load fluctuations and the hydraulic load of waste water, as well as precipitating solid particles from wastewater in the first pond, utilizing the photosynthesis process of algae as a major source of oxygen, decomposing organic matters performed biologically by microorganism (both aerobic and anaerobic), and reducing pathogenic organisms through multiple interactive processes, (Veenstra, 2000; Hayati et al, 2013).

Common problems and disruptions that often occur in wastewater treatment are primarily due to the fact that WWTPs are planned to treat domestic wastewater or wastewater from households only. In reality, the Sewon Bantul WWTP also accommodates non-domestic wastewater carried by faecal suction trucks that suck and transport wastewater from domestic industries. The wastewater needs to be processed before being discharged into the WWTP. This process may disrupt the wastewater treatment process at the WWTP.

Evaluating hydraulic characteristics in the wastewater treatment system can be done through a tracer study in the facultative stabilization pond related to the complexity of environmental factors. Therefore, environmental modeling can be quite a good alternative to evaluate hydrodynamics in the pond. The mathematical model is formulated from the chemical-biological process. It runs simultaneously with the rate of substance concentration change which is based on a non-linear differential equation system. This modeling applies the Monod equation with a time correction factor at the rate of maximum growth as indicated in Equations (1)–(13).

2. METHODOLOGY

The mass balance equations for each component of the biochemical model built in the thirteen (13) equations consist of ten nonlinear differential equations and three other kinetic equations. The thirteen (13) equations developed from the Monod equation application in relation to the time correction factor as the indication of maximum growth (Moreno-Grau et al., 1996; Situma et al., 2002; Dochain et al., 2003; Purwanto, 2005).

1. Bacterial biomass (B) *mass balance*

$$\frac{dB}{dt} = \left(\frac{B_i}{\theta} - \frac{B_e}{\theta}\right) + Y_B \mu_B \frac{OM}{K_{BOM} + OM} \frac{DO}{K_{BDO} + DO} \frac{NH_3}{K_{BNH_3} + NH_3} \frac{SP}{K_{BSP} + SP}\left(1 - \frac{B}{\eta_B}\right) B - (K_{BR} + K_{Bd}) B \qquad (1)$$

2. Algae (A) *mass balance*

$$\frac{dA}{dt} = \left(\frac{A_i}{\theta} - \frac{A_e}{\theta}\right) + \mu_A f(T) f(pH) f(L) \frac{NH_3}{K_{ANH_3} + NH_3} \frac{SP}{K_{ASP} + SP}\left(1 - \frac{A}{\eta_A}\right) A - (K_{AR} + K_{Ad} + S_A) A \qquad (2)$$

3. Zooplankton (Z) *mass balance*

$$\frac{dZ}{dt} = \left(\frac{Z_i}{\theta} - \frac{Z_e}{\theta}\right) + \mu_Z f(T) f(pH) \frac{NH_3}{K_{ZNH_3} + NH_3} \frac{SP}{K_{ZSP} + SP} \frac{DO}{K_{ZDO} + DO}\left(1 - \frac{Z}{\eta_Z}\right) Z - (K_{ZR} + K_{Zd}) Z \qquad (3)$$

4. Organic Matter (OM) *mass balance*

$$\frac{dOM}{dt}=\left(\frac{OM_i}{\theta}-\frac{OM_e}{\theta}\right)-\mu_B\frac{OM}{K_{BOM}+OM}\frac{DO}{K_{BDO}+DO}\frac{NH_3}{K_{BNH_3}+NH_3}\frac{SP}{K_{BSP}+SP}\left(1-\frac{B}{\eta_B}\right)B \quad (4)$$

5. Detritus (D) *mass balance*

$$\frac{dD}{dt}=\frac{1}{d}(S_B B+S_A A)+U_r D \quad (5)$$

6. Organic Nitrogen (ON) *mass balance*

$$\frac{dON}{dt}=\left(\frac{ON_i}{\theta}-\frac{ON_e}{\theta}\right)-\alpha_{ON}ON+T_B BK_{Bd}-T_A A(S_A-K_{Ad})+T_Z ZK_{Zd} \quad (6)$$

7. Ammonia (NH_3) *mass balance*

$$\begin{aligned}\frac{dNH_3}{dt}&=\left(\frac{NH_{3i}}{\theta}-\frac{NH_{3e}}{\theta}\right)-T_B B\left\{Y_B\mu_B\frac{OM}{K_{BOM}+OM}\frac{DO}{K_{BDO}+DO}\frac{NH_3}{K_{BNH_3}+NH_3}\frac{SP}{K_{BSP}+SP}\left(1-\frac{B}{\eta_B}\right)-K_{BR}-K_{Bd}\right\}\\&-T_A A\left\{\mu_A f(T)f(pH)f(L)\frac{NH_3}{K_{ANH_3}+NH_3}\frac{SP}{K_{ASP}+SP}\left(1-\frac{A}{\eta_A}\right)-K_{AR}-K_{Ad}\right\}\\&-T_Z Z\left\{\mu_Z f(T)f(pH)\frac{NH_3}{K_{ZNH_3}+NH_3}\frac{SP}{K_{ZSP}+SP}\frac{DO}{K_{ZDO}+DO}\left(1-\frac{Z}{\eta_Z}\right)-K_{ZR}-K_{Zd}\right\}+\alpha_{OP}ON+\frac{U_r D}{d}T_A\end{aligned} \quad (7)$$

8. *Organic Phosphorus* (OP) *mass balance*

$$\frac{dOP}{dt}=\left(\frac{OP_i}{\theta}-\frac{OP_e}{\theta}\right)-\alpha_{OP}OP+\psi_B BK_{Bd}-\psi_A A(S_A-K_{Ad})+\psi_Z ZK_{Zd} \quad (8)$$

9. *Soluble Phosphorus* (SP) *mass balance*

$$\begin{aligned}\frac{dSP}{dt}&=\left(\frac{SP_i}{\theta}-\frac{SP_e}{\theta}\right)-\psi_B B\left\{Y_B\mu_B\frac{OM}{K_{BOM}+OM}\frac{DO}{K_{BDO}+DO}\frac{NH_3}{K_{BNH_3}+NH_3}\frac{SP}{K_{BSP}+SP}\left(1-\frac{B}{\eta_B}\right)-K_{BR}-K_{Bd}\right\}\\&-\psi_A A\left\{\mu_A f(T)f(pH)f(L)\frac{NH_3}{K_{ANH_3}+NH_3}\frac{SP}{K_{ASP}+SP}\left(1-\frac{A}{\eta_A}\right)-K_{AR}-K_{Ad}\right\}\\&-\psi_Z Z\left\{\mu_Z f(T)f(pH)\frac{NH_3}{K_{ZNH_3}+NH_3}\frac{SP}{K_{ZSP}+SP}\frac{DO}{K_{ZDO}+DO}\left(1-\frac{Z}{\eta_Z}\right)-K_{ZR}-K_{Zd}\right\}+\alpha_{OP}SP+\frac{U_r D}{d}S_A\end{aligned} \quad (9)$$

10. Dissolved Oxygen (DO) *mass balance*

$$\begin{aligned}\frac{dDO}{dt}&=\left(\frac{DO_i}{\theta}-\frac{DO_e}{\theta}\right)+\frac{K_L(DO_s-DO)}{d}\\&-K\alpha_B B\left\{Y_B\mu_B\frac{OM}{K_{BOM}+OM}\frac{DO}{K_{BDO}+DO}\frac{NH_3}{K_{BNH_3}+NH_3}\frac{SP}{K_{BSP}+SP}\left(1-\frac{B}{\eta_B}\right)-K_{BR}\right\}\\&+\alpha_A A\left\{\mu_A f(T)f(pH)f(L)\frac{NH_3}{K_{ANH_3}+NH_3}\frac{SP}{K_{ASP}+SP}\left(1-\frac{A}{\eta_A}\right)-K_{AR}\right\}\\&-\alpha_Z Z\left\{\mu_Z f(T)f(pH)\frac{NH_3}{K_{ZNH_3}+NH_3}\frac{SP}{K_{ZSP}+SP}\frac{DO}{K_{ZDO}+DO}\left(1-\frac{Z}{\eta_Z}\right)-K_{ZR}\right\}\end{aligned} \quad (10)$$

11. Total Coliforms (*TC*) *mass balance*

$$\frac{dTC}{dt}=\left(\frac{TC_i}{\theta}-\frac{TC_e}{\theta}\right)-K_{TC}TC \quad (11)$$

12. Faecal Coliforms (*FC*) *mass balance*

$$\frac{dFC}{dt}=\left(\frac{FC_i}{\theta}-\frac{FC_e}{\theta}\right)-K_{FC}FC \tag{12}$$

13. *Biological Oxygen Demand* (BOD) *mass balance*

$$\frac{dBOD}{dt}=\left(\frac{BOD_i}{\theta}-\frac{BOD_e}{\theta}\right)-kBOD \tag{13}$$

2.1. Development Assumptions Model

The waste water treatment process at the WWTP unit is illustrated as a biochemical process represented as simultaneous differential equations. Dynamic modeling of domestic wastewater quality at facultative stabilization ponds is based on the assumption that the condition at the bottom of the pond is inactive. The process of biochemical model is illustrated in the following flowchart Figure 1.

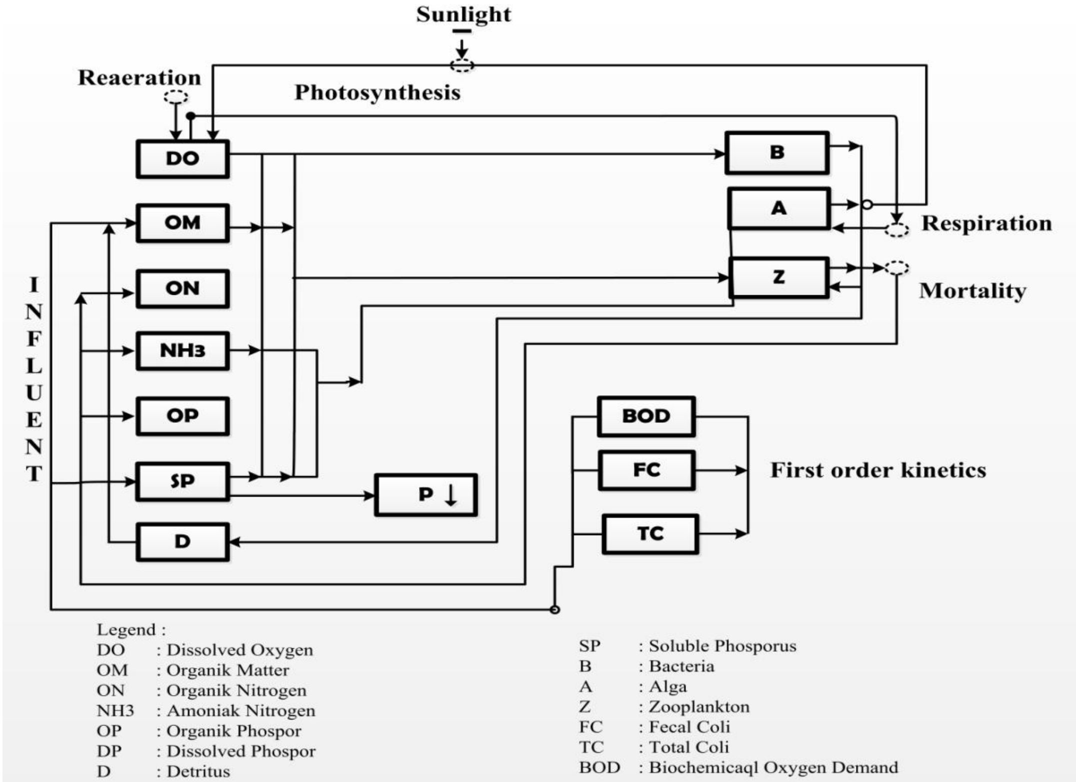

Figure 1 Flowchart of the Process of Biochemical Model

From Figure 1, the biochemical model for the rate of change or growth is developed from forming the variables in *mass balance* equations in the simultaneous differential equation system, where index *i* is the influent and *e* is the effluent.

2.2. Runge-Kutta-Fehlberg Method (RKF45) and Program Model

The thirteen non-linear differential equations are solved by applying the method of Runge-Kutta-Fehlberg (RKF45) as an integration technique to obtain the concentration for each component corresponding with the time change. The method belongs to the family of Runge-Kutta order-4 methods, but it has an accuracy rating which is up to order-5. In the thirteen systems of non linear differential equations counted simultaneously, there are forty-four (44) parameters estimated by using the "fmincon" in MATLAB (R2008a). The initial data input is : $B_0, A_0, Z_0, OM_0, D_0, ON_0, NH_{30}, OP_0, SP_0, DO_0$, TC_0, FC_0, BOD_0 (Won et al., 2005).

2.3. Validation Model

The tests of model validation use field measurement data and count data from the algorithmic model. Field data includes bacteria, algae, zooplankton, organic matter, detritus, organic nitrogen, NH_3, organic phosphorus, dissolved phosphorus, DO, total coliform, faecal coliform and BOD. The predictions using line graph with 45^o angle and the tolerance of ± 20% is used to control the quality of waste water. Statistical regression analysis with a 95% confidence interval is applied to observational data and count data. The two kinds of data are used to count the determination R^2 to show the compatibility with the field conditions.

2.4. Sample and Analysis

Wastewater samples are measured at 08:00, 10:00, 12:00, 14:00, and 16:00, respectively, and the input of model samples are measured in the facultative stabilization pond ranging from 0 m, 25 m, 50 m and 75 m, respectively, as seen in Figure 2. The samples are also measured at the inlet and outlet of the following variables involving bacteria, algae, zooplankton, organic matter, detritus, organic nitrogen, NH_3, organic phosphorus, dissolved phosphorus, DO, total coliform, faecal coliform and BOD. The method of wastewater test uses (SNI, 2005) for parametric analysis of BOD, COD, DO, phosphate, nitrate, total coliform and faecal coliform. National Standardization Agency of Indonesia (SNI) of 2004 is used to analyse nitrite and NH_4-N, while the analysis of phytoplankton and zooplankton use SNI of 1995.

Figure 2 Sewon Bantul WWTP and Sampling Point

3. RESULTS AND DISCUSSION

3.1. The Waste Stabilization Pond

Sewon Bantul WWTP has the capacity planning of 15,500 m^3/day, however, reports on the quality control of the wastewater discharge at Sewon Bantul WWTP have indicated amounts up to 10,697.53 m^3/day, which do not exceed the capacity planning limit. In 2010, Sewon Bantul WWTP served 23,000 residential connections, with an average capacity utilization of 9,700 m^3/day serving 11,000 residential connections. Urban waste that has been treated in the WWTP will be discharged into the Bedog River through concrete pipes and canals or open channels. The Bedog River is registered in the wastewater control unit as Class II, as stated in the Decree of the Governor of Yogyakarta Special Region No.214/KPTS/1991 concerning Standard Local Environmental BOD value output (effluent) below 50 mg/L. Sewon Bantul WWTP prevents wastes that will pollute rivers and contaminate groundwater in Yogyakarta and the surrounding areas. The treatment systems of biological wastewater use aeration facultative ponds, which are very simple and helpful in preventing diseases caused by waste contaminating the surface water. Recently, Sewon Bantul WWTP is only capable of serving 23% of the existing network. The data type of wastewater quality control at the inlet of the Center WWTP Public Works Department, Housing and Energy and Mineral Resources Local Government of Yogyakarta in the period of July 2010–December 2011 for Category II of quality standard parameters for BOD, temperature, pH and DO are presented in Figures 3–6.

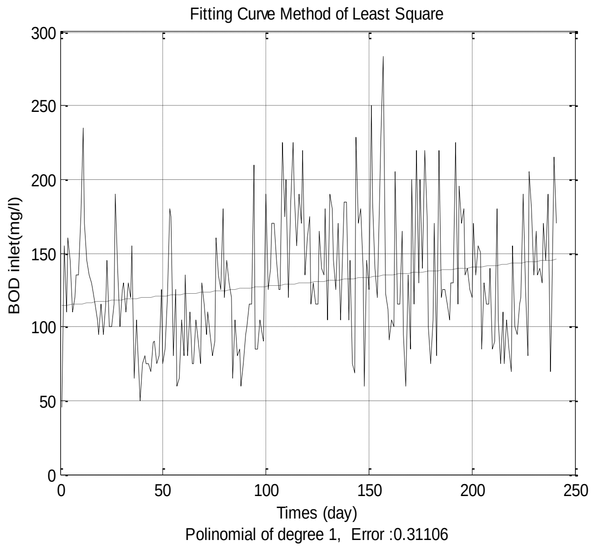

Figure 3 Typical data BOD inlet

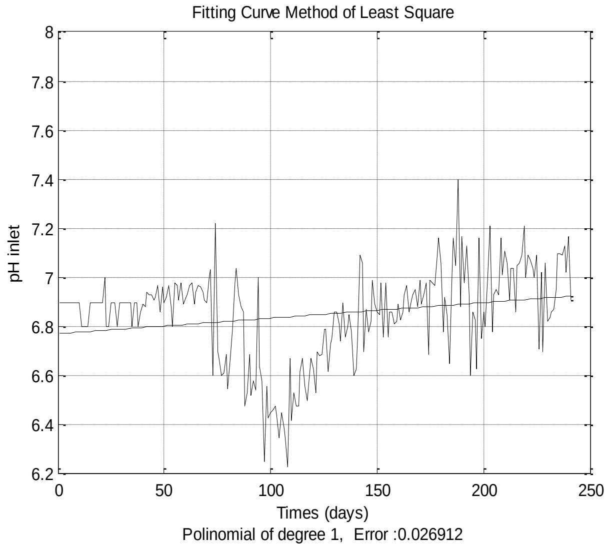

Figure 4 Typical data pH inlet

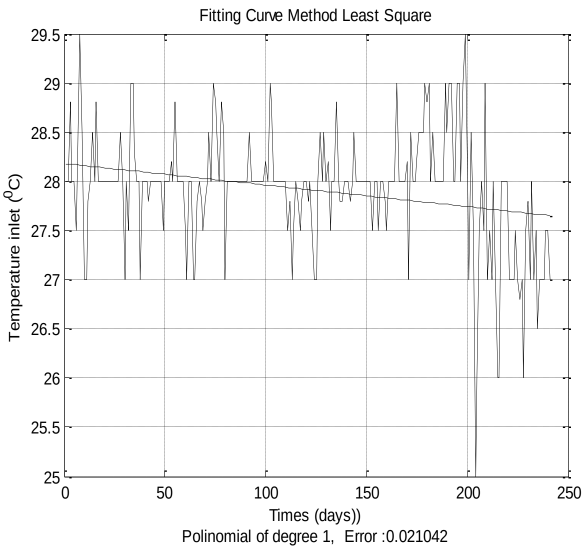

Figure 5 Typical data temperature inlet

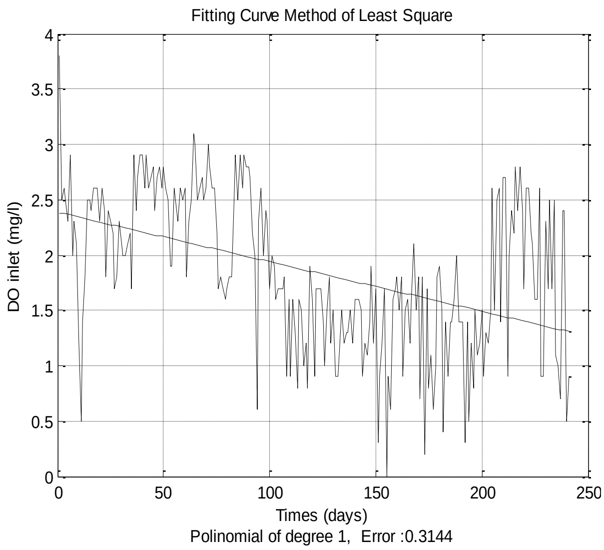

Figure 6 Typical data DO inlet

Figures 3–6 consecutively explain the waste water conditions at the inlet. The physical-chemical properties as indicated by the data smoothing are as follows: BOD concentration increasing >100 mg/L; the pH ranges at 7 showing a normal condition; temperature conditions ranging between 27^{o}C–28.5^{o}C, and DO concentration decreasing < 2.5 mg/L.

3.2. Water Quality Control of Facultative Stabilization Pond

Based on typical data at Sewon Bantul WWTP, it is necessary to conduct the evaluation of the pond performance related to the established Class II waste water quality standard. Data involving measurement of pH, temperature, DO, BOD and COD are presented in the following table.

Table 1 Wastewater quality inlet and outlet at Sewon Bantul WWTP

Times	pH		Temperature (^{o}C)		DO (mg/L)		BOD (mg/L)		COD (mg/L)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
08:00	7.09	7.12	27.8	28.8	0.9	4.2	250	16.0	752	48
10:00	7.19	7.28	27.5	28.0	1.5	3.4	165	20.0	346	72
12:00	7.19	7.14	27.0	29.5	0.8	4.2	200	18.0	700	70
14:00	7.19	7.18	28.0	30.5	1.7	4.2	155	19.5	364	64
16:00	7.35	7.00	28.0	30.0	1.8	3.7	130	19.0	368	76

Table 1 indicates that the wastewater out of the pond meets Quality Standards (QS) Group II : pH between 7.09 and 7.35 (QS = 6–9), temperatures between 28^{o}C–30^{o}C (QS = 38^{o}C), BOD between 18 mg/L–20 mg/L (QS = 50 mg/L), and COD between 48 mg/L–76 mg/L (QS = 100 mg/L).

The results of model simulations of the BOD concentration are in order. Kinetic Equation (1) describes the degradation process of the organic pollutants. The comparison of observational data and count data with the relative error of 12.72% indicates that the decrease of BOD in the model is sufficiently representative (Figure 7).

The parameter *k*, which constitutes the coefficient of the rate of degradation, is a parameter that is very sensitive to the model. In the simulation model, the *k* value is 0.6 (calibration result). After being optimized, the *k* value reaches 1.85; here, there is a considerable change in value difference of parameter *k* that reaches 1.25. This indicates that BOD concentration is very sensitive to the model. It depends on the size of the incoming wastewater stream flowing into the pond.

To determine whether the model can be applied to the concentration of BOD in the field and how it can be used as a performance evaluation means at Sewon Bantul WWTP, the following chart presents a 20% tolerance for pollutant concentration, acting as a standard for domestic waste water quality with Class II criteria as seen in Figure 8.

The DO concentration in the pond is determined by the role of sensitive parameters to the model, such as the consumption of oxygen in the metabolism of: bacterial biomass (α_B) = 2.0 (Orlob, 1982), which is optimized to 1.2; algae (α_A) = 1.0 (Orlob, 1982) which is optimized to 1.244 and zooplankton (α_Z) = 1.244 (Moreno-Grau, 1996) which is optimized to 0.5, respectively. Moreover, the DO concentration is also determined by four roles in the mechanism: (a) the consumption of oxygen by aerobic metabolism of the dead bacteria, (b) the generation and consumption of oxygen in algae photosynthesis and respiration processes, (c) the consumption of oxygen in the metabolism of zooplankton, and (d) the re-aeration between the air surface and water. The re-aeration between air surface and water is K_L at 0.8566 (Banks & Herrera, 1977).

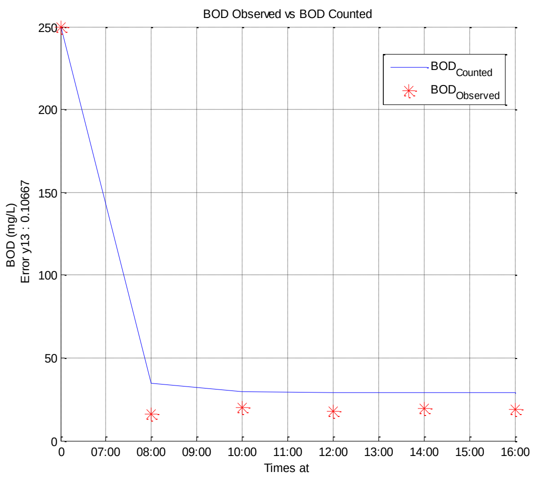

Figure 7 Comparison of BOD data and BOD count

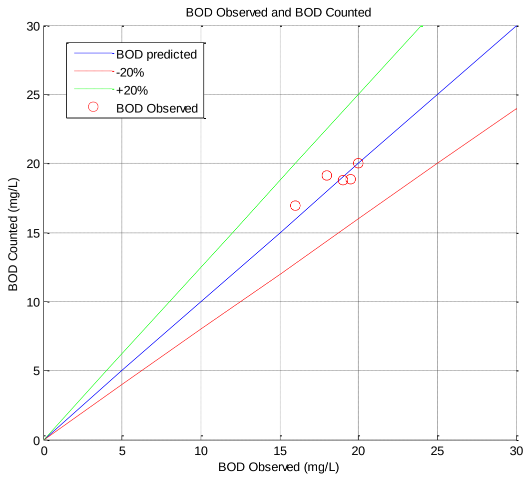

Figure 8 BOD data and BOD count tolerance of 20%

The high DO rating has a significant effect on the growth of aerobic microorganisms that will thrive and acquire adequate nutrition, which is an important factor in the growth of bacteria. DO observational data ranges from 3 to 4.2 mg/L. The DO rating for life on the water is 2 mg/L, which means aerobic microorganisms are still alive. From the results of model simulations to the DO rating, initially it has 3 mg/L showing that DO data and count DO have a relative error of 12.72%, as presented in Figure 9.

To determine whether the model can be applied to the DO concentration in the field and whether it can be used as a performance evaluation means at Sewon Bantul WWTP, a tolerance chart of 20% pollutant concentrations acted as domestic wastewater quality standard for the Class II criteria is presented in Figure 10.

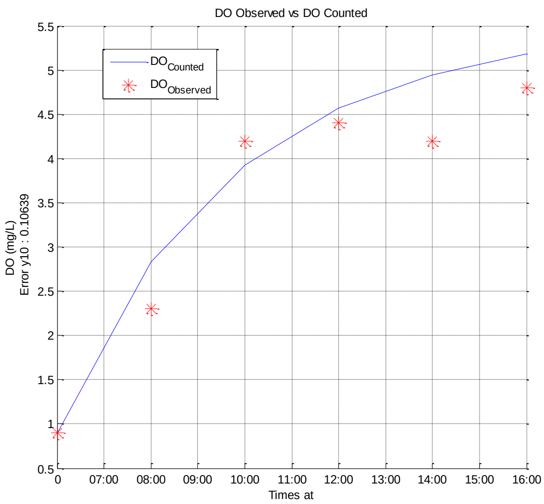

Figure 9. Comparison of DO data and DO count

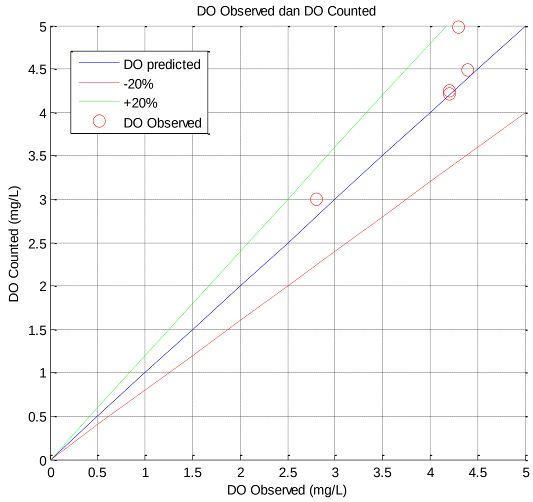

Figure 10. DO data and DO count tolerance of 20%

Based on the results of model simulations in relation to the concentration of BOD, statistical F-tests are performed by using linear regression analysis on the BOD data and count BOD, resulting in the determination of $R^2 = 0.768$ and significant $p = 0.022$, which means the ability of the wastewater treatment process at the pond to degrade organic matter is 76.8% and only

23.2% is influenced by other factors. DO is the amount of oxygen contained in the water that is used as a sign of the level of contamination of the existing waste; the more oxygen dissolves the less contamination degree it shows.

By using quadratic regression analysis (such as a model pattern), DO data and count DO, result in the determination of $R^2 = 0.819$, significant $p = 0.077$. This means that the wastewater treatment process in relation to DO concentration, as an indicator of the level of contamination of the existing waste, is 81.96% and only 18.04% is influenced by other factors. Hence, this indicates that the concentration of DO in the pond to the life of aerobic microorganisms is good.

4. CONCLUSION

Modeling which occurrs on 13 simultaneous systems of nonlinear differential equations uses the Runge-Kutta-Fehlberg (RKF45) method on a wastewater processing system for the Sewon Bantul WWTP. The findings indicate the significance of both parameters and important constants, which include a kinetic constant for bacteria respiration and kinetic constant for detrital mass. The model is adjusted according to the field conditions for a Class II wastewater quality standard. The model is used as an evaluation means to consider WWTP performance for BOD, DO and COD parameters in relation to quality controlling graphics at a 45^0 angle of tolerance with a 20% prediction line.

The research implies that the above characteristics can be applied to design similar WWTP. For researchers, environmental modeling within facultative stabilization ponds is a significant part of the environmental simulation knowledge. Therefore the same research could be developed for the similar WWTP. Futher research can be directed to observe the waste gradation level at the depth of the pond.

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