Computer Model Development on Contact-Stabilization Wastewater Treatment Systems

Priana Sudjono[1], Park Sang Sook[2] and A. Cahyo[1]

[1]Dept. of Environmental Engineering - ITB
Fax +62 022 2534166; Email: memteq@ bdg.centrin.net.id
[2]Dept of Environmental Engineering
Sunchon University Korea

Abstract. Computer model is developed to relate parameters that determine the performance of a contact-stabilization system. Based on mass and substrate balance in the system, relationships between the variables are developed, then simulations using various values of the parameters can produce trend lines indicating the behavior of a system as well as the required conditions to reach an expected performance. When the operating conditions, such as recycled sludge and wasted sludge are changed, the model demonstrates alterations of the performance consistent to the developed mathematical relationships. Additionally, the computer model shows that the results could produce further explanation on phenomena of biological processes in contact-stabilization systems.

***Keywords**: computer model, contact-stabilization, recycled sludge, wasted sludge.*

Pembuatan Komputer Model pada Sistim Pengolahan Air Buangan Kontak-Stabilisasi

Sari. Suatu komputer model dibuat untuk menghubungkan parameter yang menentukan kinerja suatu sistim kontak-stabilisasi. Berdasarkan atas keseimbangan masa dan keseimbangan substrat didalam sistim, dibuat hubungan antara variabel, kemudian simulasi mempergunakan berbagai harga parameter dapat menghasilkan garis kecenderungan yang menunjukkan perilaku suatu sistim demikian pula kondisi yang dibutuhkan untuk mencapai kinerja yang diharapkan. Bilamana kondisi operasi, seperti sirkulasi lumpur dan pembuangan lumpur, diubah, model menunjukkan perubahan kinerja konsisten terhadap persamaan matematik yang dikembangkan. Selanjutnya, model menunjukkan bahwa hasil hitungan dapat menjelaskan lebih jauh phenomena proses biologi di sistim kontak-stabilisasi.

***Kata kunci**: komputer model, kontak-stabilisasi, sirkulasi lumpur, lumpur terbuang.*

1 Introduction

Contact-stabilization system is a biological wastewater treatment modified from activated sludge. In this case the process is separated into two different tanks, absorption process takes place in contact tank and then oxidation, when absorptive organic are metabolically assimilated, in stabilization tank. Concerning several variables involved in determining the efficiency of the systems, a mathematical model is required to justify the performance of the system quantitatively.

Research on contact-stabilization system had been done in laboratory and in field plants. Laboratory experiments modified detention time and sludge age to understand the behavior of a scaled system in treating wastewater from a textile industry [1,2]. Moreover, Dewanti [3] added recycled sludge as a variable to specify performance of a scaled system in treating the same wastewater. They found different optimum results, so that to analyze the performance of a system, further exploitations on the variables are necessary. In the research, mathematical relationships to be implied in a computer model have been developed then, through simulations, operations of a full-scaled system can be imitated.

The model is developed based on steady state conditions and the wasted sludge is discharged from the stabilization tank. Then simulations apply detention time as a fix variable, while recycled sludge and the amount of wasted sludge are placed as independent variables. Other data are the same as those in the laboratory experiments, so that comparisons to the simulation results and analyses on trend lines will explain the behavior of the system.

2 Method

2.1 Governing Equation

The governing equations are based on an assumption that the system is under a steady state condition. Additionally, there is no microorganism's activity in clarifier, and growth-yield coefficients in both tanks are similar. Mathematical model is derived from a system as schematized in Figure 1.

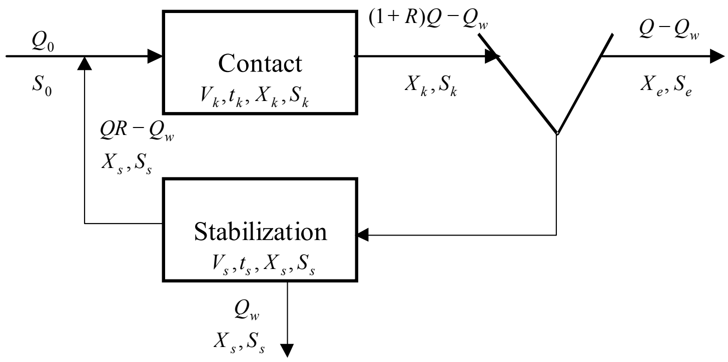

Figure 1 The diagram on contact-stabilization systems

The volume of the tanks:

$$V_k = (Q + Q.R - Q_w).t_k \quad (1)$$

$$V_s = (Q.R).t_s \quad (2)$$

2.2.1 Mass Balance

The principle of mass balance, as described elsewhere, is applied in every unit in the system.

Rate of mass accumulated = rate of mass in influent – rate of mass in effluent + rate of mass growth in the systems

Contact tank

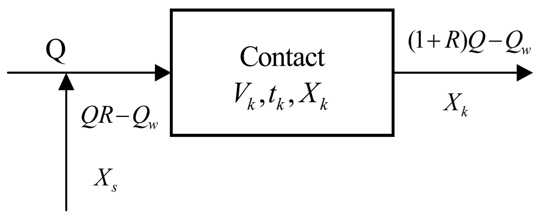

Figure 2 Mass balance in contact tank

The equation on mass balance in contact tank is:

$$\left(\frac{dX}{dt}\right)_k .V_k = (Q.R - Q_w).X_s - (Q.R + Q - Q_w).X_k + V_k.\mu_k.X_k \qquad (3)$$

In steady state condition, $dX/dt = 0$.

So that, the following function can be written as

$$\frac{X_k}{X_s} = f\left(R, Q_w, t_k, \frac{1}{(1-\mu_k)}\right) \qquad (4)$$

Clarifier

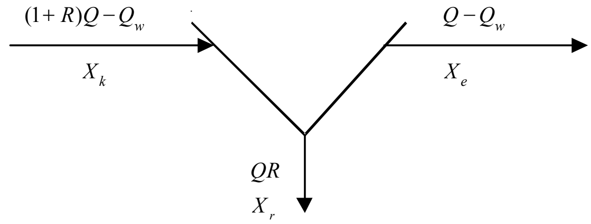

Figure 3 Mass balance in clarifier

The equation on mass balance in clarifier is:

$$(Q.R + Q - Q_w).X_k = Q.R.X_r + (Q - Q_w).X_e \qquad (5)$$

Assuming that the effluent does not content microorganisms: $X_e = 0$

Then, it is found that

$$X_r = f(Q, R, Q_w, X_k) \qquad (6)$$

Stabilization tank

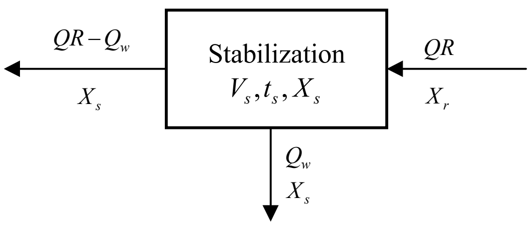

Figure 4 Mass balance in stabilization tank

The equation on mass balance in stabilization tank is :

$$\left(\frac{dX}{dt}\right)_s .V_s = Q.R.X_r - (Q.R - Q_w)X_s - (Q_w.X_s) + V_s.\mu_s.X_s \tag{7}$$

Assuming that the system is operated in steady state conditions:

$dS/dt = 0$; so that the composition of microorganisms in the system can be written in a function as

$$\frac{X_k}{X_s} = f\left(R, Q_w, t_s, (1-\mu_s)\right) \tag{8}$$

Sludge age is the length of time that sludge stays in a system, so

$$\theta_C = \frac{V_k.X_k + V_s.X_S}{Q_W.X_S - Q_i.X_i + Q_e.X_e} \tag{9}$$

Assuming that there is no microorganism in influent and effluent: $X_i = X_e = 0$, and substituting equation (1), and (2) into (9), then

$$\theta_c = f\left(\frac{X_k}{X_s}, Q, Q_w, R, t_k, t_s\right). \tag{10}$$

Rearranging function (10), the following relationships can be found

$$\frac{X_k}{X_s} = f(\theta_c, t_k, t_s, Q, R, Q_w) \tag{11}$$

$$R = f\left(Q_w, Q, t_k, t_s, \theta_c, \frac{X_k}{X_s}\right) \tag{12}$$

2.1.2 Substrate balance

The principle of substrate balance, as described elsewhere, is applied in every unit in the system.

Rate of substrate accumulation = rate of influent substrate – rate of effluent substrate + rate of removal

Derivation of equations is based on substrate balance and adopts an assumption that Growth Yield coefficient of the microorganisms in both tanks is similar, or $Y = Y_k = Y_s$.

Contact tank

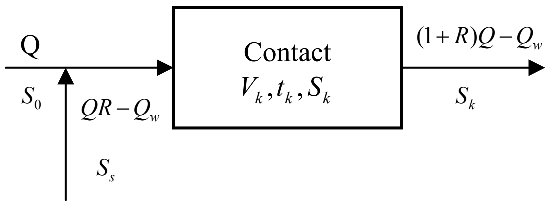

Figure 5 Substrate balance in contact tank

The substrate balance equation can be written as:

$$\left(\frac{dS}{dt}\right)_k . V_k = Q.S_o + (Q.R - Q_w).S_s - (Q.R + Q - Q_w).S_k - \frac{V_k.X_k.\mu_k}{Y} \qquad (13)$$

Assuming that the system is operated in steady state condition:

$dS/dt = 0$, so that,

$$(Q + Q.R - Q_w).S_k = Q.S_o + (Q.R - Q_w).S_s - \frac{V_k.X_k.\mu_k}{Y} \qquad (14)$$

Equation (14) will be able to calculate S_k where the function will be:

$$S_k = f(Q, S_0, S_s, R, Q_w, V_k, X_k, Y, \mu_k, t_k) \qquad (15)$$

Clarifier

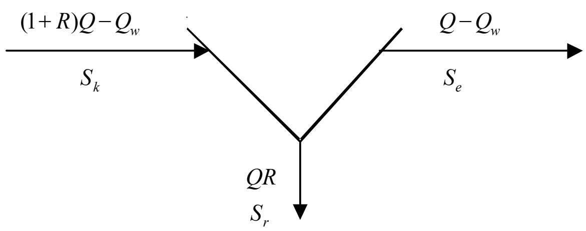

Figure 6 Substrate balance in clarifier

The substrate balance equation can be written as:

$$(Q.R + Q - Q_w).S_k = (Q - Q_w).S_e + (Q.R.S_r) \qquad (16)$$

So, it is clear that

$$S_r = f(Q, R, Q_w, S_e, S_k) \tag{17}$$

and,

$$S_e = f(Q, R, Q_w, S_r, S_k) \tag{18}$$

In case there is no microorganism's activity in clarifier, the above functions should adopt $S_k = S_r = S_e$

Stabilization tank

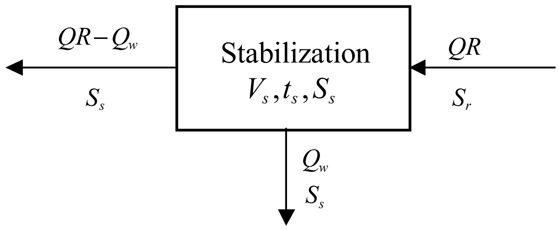

Figure 7 Substrate balance in stabilization tank

The substrate balance equation can be written as:

$$\left(\frac{dS}{dt}\right)_s . V_s = Q.R.S_r - (Q.R - Q_w).S_s - Q_w.S_s - \frac{V_s.X_s.\mu_s}{Y} \tag{19}$$

Assuming that the system is operated in steady state conditions:

$dS/dt = 0$; so that,

$$(Q.R - Q_w).S_s + Q_w.S_s = Q.R.S_r - \frac{V_s.X_s.\mu_s}{Y} \tag{20}$$

Rearranging equation (20) substrate in stabilization tank can be defined as:

$$S_s = f(S_k, X_s, \mu_s, Y, t_s) \tag{21}$$

Rearranging equation (21) by substituting equation (2), the following function can be written:

$$S_k = f(Q, S_0, R, Q_w, X_k, X_s, \mu_s, \mu_k, Y, t_s, t_k) \tag{22}$$

Efficiency

Based on substrate balance, a mathematical model on efficiency of the systems can be developed. The model relates substrate removal, hydraulic detention time in contact tank and stabilization tank, sludge recycle, and sludge age.

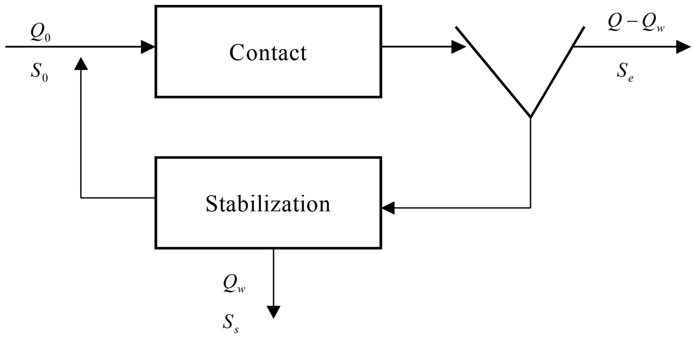

Figure 8 Contact-stabilization system for efficiency model

A principle applied in computing efficiency of the system:

rate of substrate weight in the influent = rate of substrate weight in the effluent

Incoming mass into the systems:

$$Q.S_o = (Q - Q_w).S_e + Q_w.S_s + \frac{\mu_k.X_k.V_k}{Y} + \frac{\mu_s.X_s.V_s}{Y} \quad (23)$$

The mass in the effluent:

$$Q.(S_o - S_e) = Q_w.(S_s - S_e) + \frac{\mu_k.X_k.V_k + \mu_s.X_s.V_s}{Y} \quad (24)$$

The efficiency: $\eta = \dfrac{S_0 - S_e}{S_0}$ (25)

Substituting equation (23) and (24) into (25), it is found that

$$S_0 - S_e = f(Q, Q_w, R, X_k, X_s, \mu_k, \mu_s, X_k, X_s, t_k, t_s, Y) \quad (26)$$

However, the equation of efficiency is not simple but many variables involve in the equation. The most crucial variable should be known is the amount of microorganism in the tanks. So that, the function on efficiency is rewritten as the following relations:

$$\frac{\eta}{X_k} = f(S_0, Q, \theta_c, t_s, t_k, \mu_k, \mu_s, R, Q_w, Y) \tag{27}$$

$$\frac{\eta}{X_s} = f(S_0, Q, \theta_c, t_s, \mu_k, \mu_s, R, Q_w, Y) \tag{28}$$

Using substrate balance relationships, the efficiency of the system can be written as; $\eta = f(S_0, Q, X_k, X_s, \theta_c, t_k, t_s, \mu_k, \mu_s, R, Q_w, Y)$ (29)

Note:

Q, Q_e, Q_w	: flow of influent, effluent, and wasted sludge
R	: sludge recycle ratio
V_k, V_s	: volume of contact tank and stabilization tank
S_0, S_k, S_s, S_e	: substrate concentration in influent, contact tank, stabilization tank and effluent
X_k, X_s, X_r, X_e	: concentration of microorganism in contact tank, stabilization tank, recycled sludge, and effluent
t_k, t_s	: detention time in contact tank, and stabilization tank.
μ_k, μ_s	: specific growth rate of microorganism in contact and stabilization tank
Y	: growth yield coefficient
θ_c	: sludge age
η	: overall efficiency of a system

2.2 Formulae Transformation

The formulae on contact stabilization-systems are transformed into a computer model using FORTRAN. The model is designed for simulation based on values of detention time and specific growth rate. Flowchart of the computer program is shown in Figure 9.

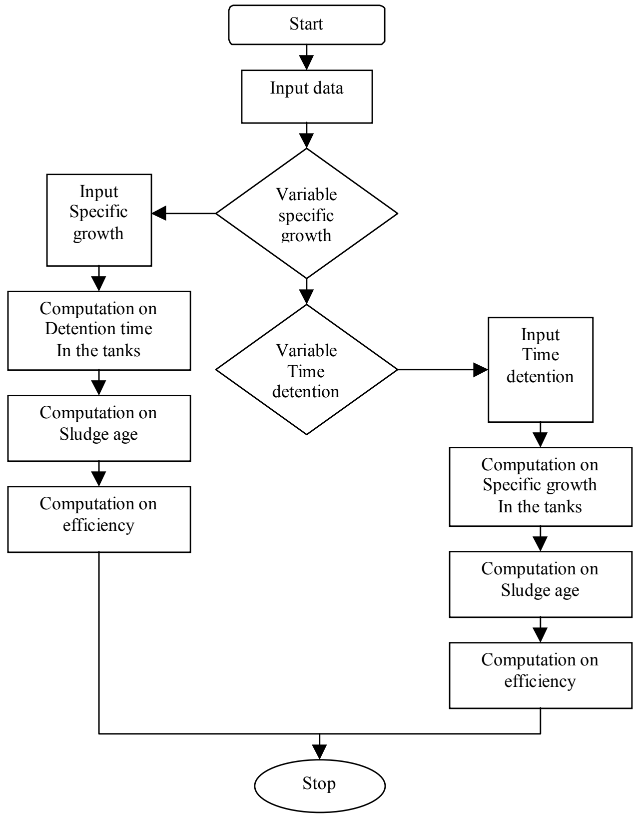

Figure 9 The flowchart of the computer model on Contact-Stabilization System

2.3 Simulation

Simulation using the computer model is conducted using physical data of a reactor that is used in laboratory experiment. The results can be compare to find the reasons on similarities and differences when several values of detention time or wasted sludge are adopted. These mean that the results from laboratory experiments will be approached by several reactor dimensions and several types of operations. Tables showing relationships between variables such as X_k / X_s , μ_k , μ_s , θ_c , and η can lead to understanding on behavior of wasted sludge and recycled sludge.