

THE KINETIC ANALYSIS OF BOD AND NITROGEN REMOVAL IN AN OXIDATION DITCH

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ABSTRACT

The simultaneous removal of nitrogen as well as organic substances is one of important characteristics of the oxidation ditch process. To describe this phenomena, synthetic kinetic models including the rates of BOD oxidation, nitrification, denitrification, DO and alkalinity changes, and sludge growth were proposed in this study. Rate equations for these mechanisms were mainly based on Monod type kinetics taking into account several limiting effects among these mechanisms. To develop the design procedure, these kinetic models were combined with the tank-in-series model having circulating and back flows. They were analyzed numerically for typical design and operating conditions. From these computer simulations, successful results to explain these complicated phenomena and several design and operating bases were obtained.

KEYWORDS

Oxidation ditch ; kinetics ; BOD oxidation ; nitrification ; denitrification.

INTRODUCTION

Recently in Japan, much attention has been devoted to the oxidation ditch process as a small scale simple sewage treatment process, which is needed especially for the sewage system in rural areas. This process has the following principal advantages : 1) easy maintenance and lower operating cost, 2) less production of excess sludge, and 3) reduction of nitrogen as well as BOD.

The oxidation ditch process circulating the mixed liquor in an oval ditch is one of many activated sludge processes. The main operating conditions and representative values are BOD loading : 0.1-0.2 kgBOD/m³.day, BOD·SS loading : 0.03-0.05 kgBOD/kgSS·day, MLSS : 3000-4000 mg/l, sludge retention time : 15-30 days, aeration time : 24-48 hours, return sludge ratio : 50-150%. The removal efficiencies reported are 90-95% of BOD and SS, 50-90% of Total-N, and 30-60% of Total-P.

The stable and relatively high removal efficiency, especially for BOD and nitrogen, can be explained by the following facts :

1) The circulating flow is steady and concentrations are stable and low, because

the feed is diluted 50-300 times with the circulating mixed liquor.

2) The DO distribution decreasing in the flow direction, that gives a suitable condition to denitrifying bacteria, is established by using a brush or caged rotor aerator placed across the ditch at only one or two positions.

3) Nitrifying and denitrifying bacteria are hardly washed out, because the less the amount of excess sludge becomes, the larger the sludge retention time (SRT) becomes.

Although the oxidation ditch process has noticeable characteristics, the mechanism of removal is very complicated, and the modeling of the phenomena has not been established, because BOD oxidation, nitrification, and denitrification occur concurrently and successively.

These reactions are concerned with many factors such as DO, pH, temperature and alkalinity among others, as shown in Table 1.

Table 1 Factors Influencing BOD oxidation, Nitrification & Denitrification

	Temperature	pH	DO	Alkalinity	BOD	NH ₄	NOx	Biomass
BOD oxidation	○	○	○		○			○
Nitrification	○	○	○	○		○		○
Denitrification	○	○	○		○		○	○

○ : large influencing factor

The oxidation ditch process for BOD and nitrogen removal can be regarded as the process having both of the functions of a single sludge nitrification-denitrification process and an extended aeration process. Therefore, the modeling of kinetics is performed based on Ishikawa's study¹⁾ of the nitrification and denitrification in nightsoil treatment and Batchelor's research²⁾ on a single-sludge system.

KINETIC DEVELOPMENT

In biological waste water treatment, the metabolic reactions of oxidized, nitrified, nitrified, denitrified, and denitrified bacteria could be fifteen, as shown in Table 2, corresponding to their respiration, growth, and endogenous respiration stages. For the oxidation ditch process in which all of these reactions are probable, however, it is difficult and impractical to develop the kinetic models based on all of them. Therefore, the following assumptions are taken as practical simplifications :

(A) Bacteria biomass is not considered in every species. The sum of all bacteria is regarded as one kind of the biomass to be considered. Every species of bacteria in the biomass acts as a metabolic tissue.

(B) The sum of nitrite and nitrate is indicated as NOx, which is only one form of oxidized nitrogen. Because high nitrite concentrations are not usually observed in the oxidation ditch process, the rates of nitrification and denitrification are taken to be proportional to the removal rates of ammonia and NOx, respectively. From these assumptions, fifteen metabolic reactions in Table 2 can be reduced to nine, consisting of oxidizing, nitrifying and denitrifying reactions.

BOD removal

For an ordinary activated sludge process, the kinetic model of BOD removal has almost been established by many investigators. For the single reactor in which

Table 2 Classification of Metabolic Reaction

	Respiration	Growth	Endogenous Resp.
Aerobes	$\begin{array}{ccc} CxHyOz & & O_2 \\ (BOD) & & \\ \swarrow & & \searrow \\ K_{11} & & X_1 \\ \swarrow & & \searrow \\ CO_2 & & H_2O \\ (NH_3) & & \end{array}$	$\begin{array}{ccc} CxHyOz & & O_2 \\ NH_3 & & \\ \swarrow & & \searrow \\ K_{12} & & X_1 + dX_1 \\ \swarrow & & \searrow \\ CO_2 & & H_2O \end{array}$	$\begin{array}{ccc} & & O_2 \\ & & \swarrow \\ & & K_{13} \\ & & \searrow \\ & & X_1 - dX_1 \\ \swarrow & & \searrow \\ CO_2 & & H_2O \\ NH_3 & & \end{array}$
Nitrite B.	$\begin{array}{ccc} NH_3 & & O_2 \\ \swarrow & & \searrow \\ K_{21} & & X_2 \\ \swarrow & & \searrow \\ NO_2 & & H^+, H_2O \end{array}$	$\begin{array}{ccc} NH_3 & & O_2 \\ CO_2 & & \\ \swarrow & & \searrow \\ K_{22} & & X_2 + dX_2 \\ \swarrow & & \searrow \\ NO_2 & & H^+, H_2O \end{array}$	$\begin{array}{ccc} & & O_2 \\ & & \swarrow \\ & & K_{23} \\ & & \searrow \\ & & X_2 - dX_2 \\ \swarrow & & \searrow \\ NO_2 & & H^+, H_2O \\ CO_2 & & \end{array}$
Nitrate B.	$\begin{array}{ccc} NO_2 & & O_2 \\ \swarrow & & \searrow \\ K_{31} & & X_3 \\ \swarrow & & \searrow \\ NO_3 & & \end{array}$	$\begin{array}{ccc} NH_3 & & O_2 \\ NO_2 & & \\ CO_2 & & \\ \swarrow & & \searrow \\ K_{32} & & X_3 + dX_3 \\ \swarrow & & \searrow \\ NO_3 & & H^+, H_2O \end{array}$	$\begin{array}{ccc} & & O_2 \\ & & \swarrow \\ & & K_{33} \\ & & \searrow \\ & & X_3 - dX_3 \\ \swarrow & & \searrow \\ NO_3 & & H^+, H_2O \\ CO_2 & & \end{array}$
Denitrifier B.	$\begin{array}{ccc} NO_3 & & CxHyOz \\ \swarrow & & \searrow \\ K_{41} & & X_4 \\ \swarrow & & \searrow \\ NO_2 & & CO_2, H_2O \end{array}$	$\begin{array}{ccc} NO_3 & & CxHyOz \\ \swarrow & & \searrow \\ K_{42} & & X_4 + dX_4 \\ \swarrow & & \searrow \\ CO_2 & & H_2O \\ & & OH^- \end{array}$	$\begin{array}{ccc} & & NO_3 \\ & & \swarrow \\ & & K_{43} \\ & & \searrow \\ & & X_4 - dX_4 \\ \swarrow & & \searrow \\ NO_2 & & CO_2, H_2O \end{array}$
Denitrifier B.	$\begin{array}{ccc} NO_2 & & CxHyOz \\ \swarrow & & \searrow \\ K_{51} & & X_5 \\ \swarrow & & \searrow \\ N_2 & & CO_2, H_2O \\ & & OH^- \end{array}$	$\begin{array}{ccc} NO_2 & & CxHyOz \\ \swarrow & & \searrow \\ K_{52} & & X_5 + dX_5 \\ \swarrow & & \searrow \\ CO_2 & & H_2O \\ & & OH^- \end{array}$	$\begin{array}{ccc} & & NO_2 \\ & & \swarrow \\ & & K_{53} \\ & & \searrow \\ & & X_5 - dX_5 \\ \swarrow & & \searrow \\ N_2 & & CO_2, H_2O \\ & & OH^- \end{array}$

BOD removal and denitrification occur concurrently, however, it is necessary to take further into account the loss of BOD that is caused by the denitrification, as shown by the mass balance equation (1).

The sum of BOD removed = (the loss by oxidation) + (the loss by denitrification) (1)

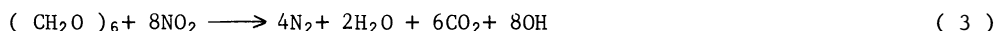
The kinetic model for this case, therefore, is expressed as follows, based on the Monod type kinetics :

$$\frac{1}{X} \frac{dS}{dt} = - \frac{Us \cdot S}{Ks + S} - \frac{DO}{Ko + DO} - \alpha \left(\frac{dCa}{dt} \right)_B \quad (2)$$

- where
- X : biomass of MLVSS (mg/l)
 - S : concentration of BOD (mg/l)
 - Us : maximum rate of BOD removal (hr⁻¹)

- K_s : saturation coefficient for BOD (mg/l)
 DO : concentration of dissolved oxygen (mg/l)
 K_o : saturation coefficient for DO (mg/l)
 (dC_3/dt) : rate of denitrification
 α : exchange coefficient (g/g)

As indicated by the right hand first term, BOD oxidation is influenced by the DO concentration. This idea has been adopted by a few scholars³⁾. The right hand second term is introduced based on the above consideration. The exchange coefficient can be calculated by the following equations :



When nitrite and nitrate are denitrified, the theoretical oxygen demands (ThOD) in Eq. (3) and (4) are calculated to be 1.71 and 2.85 g per nitrogen unit gram, respectively. By assuming that BOD is equal to 2/3 ThOD, the exchange coefficients become 1.14 and 1.90 respectively.

Nitrification

Nitrifying bacteria are autotrophic and perform respiration. The nitrifying reaction rate is usually expressed by Monod's kinetics.

$$-\frac{dN}{dt} = \frac{U_n \cdot N}{K_n + N} \quad (5)$$

where dN/dt : the rate of nitrification (mg/l·hr)
 U_n : maximum rate of ammonia removal (hr⁻¹)
 K_n : saturation coefficient for ammonia (mg/l)
 N : concentration of ammonia (mg/l)

In most cases, the K_n value is small (0.5-2 mg/l). Therefore, this rate can be shown as a zero-order reaction.

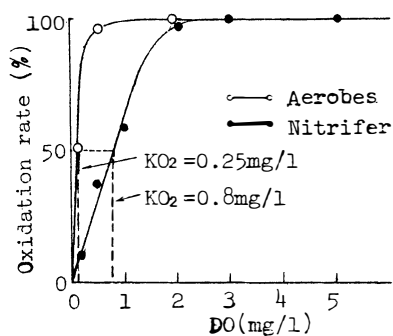


Fig.1 The effect of DO on the rate of oxidation by Aerobes and Nitrifer

The relationship between the nitrifying rate and the DO concentration is shown in Fig.1. The nitrifying rate is largely influenced by dissolved oxygen. When DO is below 0.2 mg/l, the nitrifying reaction occurs very slowly, but when DO is more than 2.0 mg/l, it proceeds rapidly.

Although the influence of pH on nitrification has been investigated extensively,

the influence of alkalinity has scarcely been studied.

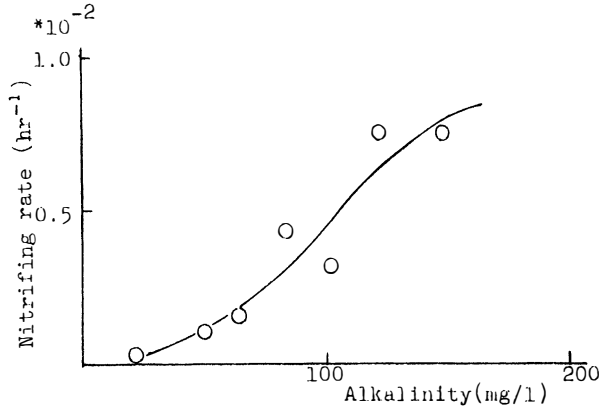


Fig.2 The effect of alkalinity on the nitrification rate

From Fig.2, which was obtained by the authors⁴⁾ from experiments on nitrification and denitrification in an aeration tank, it is observed that the nitrifying rate decreases at an alkalinity below 150 mg/l. Almost all of the waste water in Japan shows an alkalinity below 150 mg/l.

Consequently, the authors propose the following kinetic model taking account of the influences of DO and alkalinity :

$$\frac{1}{X} \frac{dC_1}{dt} = - \frac{U_1 \cdot C_1}{K_1 + C_1} \cdot \frac{DO}{K_o + DO} \cdot \frac{A}{K_a + A} \quad (6)$$

where

- C_1 : concentration of ammonia-nitrogen (mg/l)
- U_1 : maximum rate of nitrification (hr⁻¹)
- K_1 : saturation coefficient for nitrification (mg/l)
- K_o : saturation coefficient for DO (mg/l)
- A : concentration of alkalinity (mg/l)
- K_a : saturation coefficient for alkalinity (mg/l)

U_1 and K_1 are the same as U_n and K_n , respectively. The value of K_a obtained from Fig.2 is 100 mg/l.

Overall change of NO_x-N

It is stressed that denitrification, such as that observed in the oxidation ditch or aerobic digestion processes, takes place concurrently with nitrification, in one reactor. Many investigations including that of Pasveer⁵ and the authors¹ have shown this fact. On this point, the oxidation ditch process differs fundamentally from the separated processes for nitrification and denitrification. From these considerations, combining the nitrification rate shown by Eq.(6) and denitrification rate described below, the overall change of NO_x-N can be expressed as follows:

$$\frac{1}{X} \frac{dC_2}{dt} = \frac{U_1 \cdot C_1}{K_1 + C_1} \cdot \frac{DO}{K_o + DO} \cdot \frac{A}{K_a + A} - \frac{U_2 \cdot C_2}{K_2 + C_2} \cdot \frac{S}{K_s + S} \cdot \left(1 - \frac{DO}{K_o + DO} \right) \quad (7)$$

where

- C_2 : NO_x-N (mg/l)
- U_2 : maximum rate of denitrification (hr⁻¹)
- K_2 : saturation coefficient for denitrification (mg/l)

Denitrification

Denitrifying microorganisms are facultative and heterotrophic bacteria which need

organic carbon for denitrification. In the oxidation ditch process, a portion of the organic substances in the influent and mixed liquor is consumed as the electron donor. Consequently, the denitrification in an oxidation ditch is probably influenced by the relatively low concentration of BOD. On the other hand, many studies on denitrification indicate that there exists DO inhibition. Bauman⁷) maintained that the DO concentration of 0.5 mg/l was the highest limit for denitrification. Sharma et al) showed that the influence of DO could be based on Monod type kinetics, and they obtained the saturation coefficient (K_o) of 0.1 mg/l.

From these considerations, the nitrogen gas generation by denitrification can be shown as follows assuming Monod type kinetics for NO_x-N , BOD and DO :

$$\frac{1}{X} \frac{dC_3}{dt} = \frac{U_2 \cdot C_2}{K_2 + C_2} \cdot \frac{S}{K_s + S} \cdot \left(1 - \frac{DO}{K_o + DO} \right) \quad (8)$$

Sludge growth and DO and alkalinity changes

As indicated above, the concentrations of sludge as biomass and DO are principal factors controlling the rate of BOD oxidation, nitrification and denitrification. Also, alkalinity is closely related to nitrification. The changes of these are written as follows :

$$\frac{dX}{dt} = a \left(\frac{dS}{dt} \right)_B + b \left(\frac{dC_1}{dt} \right)_B + c \left(\frac{dC_3}{dt} \right)_B - dX \quad (9)$$

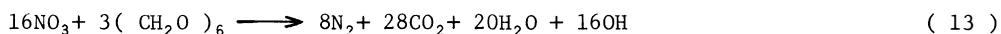
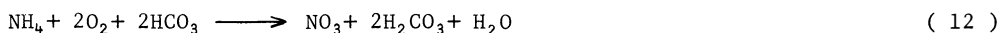
$$\frac{dDO}{dt} = -a' \left(\frac{dS}{dt} \right)_B - b' \left(\frac{dC_1}{dt} \right)_B - d'X + K_{La} (DO_s - DO) \quad (10)$$

$$\frac{dA}{dt} = -e \left(\frac{dC_1}{dt} \right)_B + f \left(\frac{dC_3}{dt} \right)_B \quad (11)$$

where

- a : yield coefficient of the removal of BOD
- b : yield coefficient for nitrification
- c : yield coefficient for denitrification
- d : microbial decay coefficient (hr⁻¹)
- a' : oxygen-use coefficient for BOD oxidation
- b' : oxygen- use coefficient for nitrification
- d' : oxygen- use coefficient for energy of maintenance (hr⁻¹)
- K_{La} : over-all oxygen transfer rate (hr⁻¹)
- DO_s : saturation concentration of dissolved oxygen
- e : decrease of alkalinity for nitrifying
- f : increase of alkalinity for denitrifying

The Eq. (9) consists of the rate of biomass sludge growth from BOD oxidation , nitrification, and denitrification and the rate of biomass consumption by endogenous respiration. The values of the coefficients a,b,c,d were obtained from the literature¹⁾⁻⁴⁾ on the treatment of domestic waste water. Eq. (10) shows that the change of DO comes from the BOD oxidation, nitrification, sludge decay, and oxygen supply. In the case of the oxidation ditch process, it must be noticed that the waste water is aerated partially and that overall oxygen transfer rate coefficient K_{La} reflects the effect on oxygen transfer from the water surface as well as from the aerator. The Eq.(11) represents the alkalinity change due to consumption by nitrification and production by denitrification. These biochemical reactions are shown as follows :



From Eq.(12) and (13), the alkalinity consumption and production are

calculated to be 7.14 and 3.57 g as CaCO₃ per unit gram of nitrogen, respectively.

MIXING DESCRIPTION

Another important problem concerned with the oxidation ditch process is the description of the mixing regime. Mixing in an aeration tank is classified into four types, complete mixing, plug-flow, tank-in-series, and dispersion models. For the oxidation ditch process, it is necessary to take account of the back-flow as well as the circulation flow, as shown in Fig.3.

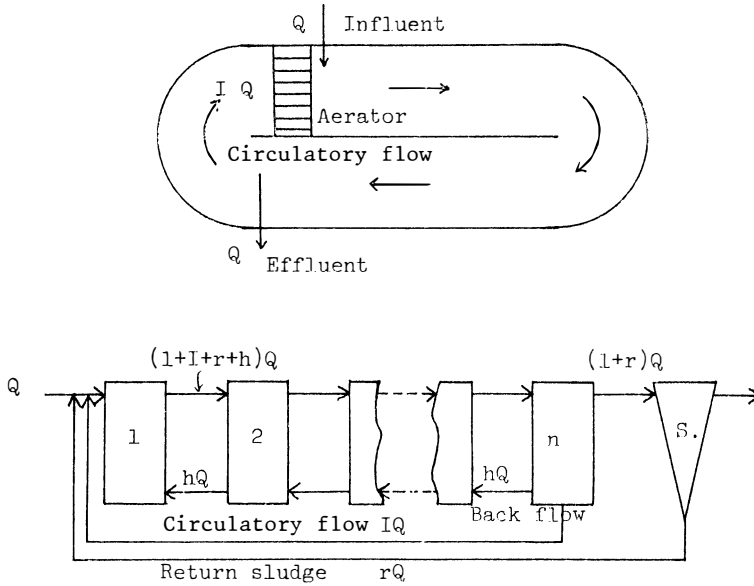


Fig.3 Schematic of oxidation ditch and tank-in-series model

Therefore, the authors adopted the following mixing model proposed by Ishikawa one of the authors, which is the tank-in-series model including back-flow :

Material balance

The first tank

$$\frac{V}{n} \frac{dC}{dt} = Q \{ C_0 + (I + r)C_n + hC_2 - (1+h+I+r)C_1 \} \quad (14)$$

The i th tank

$$\frac{V}{n} \frac{dC_i}{dt} = Q \{ (1+h+I+r)C_{i-1} + hC_{i+1} - (1+2h+I+r)C_i \} \quad (15)$$

The n th tank

$$\frac{V}{n} \frac{dC_n}{dt} = Q (L+h+I+r)(C_{n-1} - C_n) \quad (16)$$

Initial conditions

$$\begin{aligned} C_i &= 0 && \text{at } t=0 \\ C &= C^0 V/Q \delta(t) && \text{at } C_i \neq 0 \end{aligned} \quad (17)$$

where C , C_i , C_n : concentrations of 1st, i th, and n th tank (mg/l)
 V : tank volume (m^3)
 n : tank number
 C^v : average concentration in the tank (mg/l)
 $\delta(t)$: Dirac's δ function
 Q : feed-flow (m^3 /day)
 I : circulation flow ratio
 h : back-flow ratio
 r : return sludge ratio

For the ditch divided into ten tanks, the degree of mixing was calculated by these equations and the Dirac's delta response method.

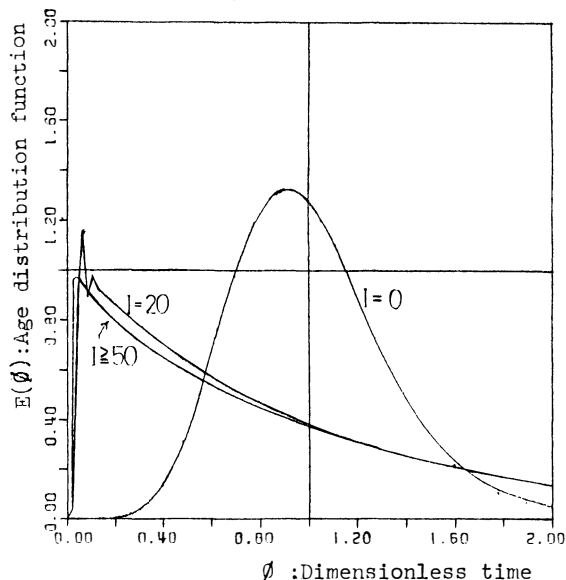


Fig.4 Delta response for circulation flow ($n=10.0$, $h=0.0$)

Fig.4 shows the concentration responses to the delta input under several circulation-flow ratios (0-50 Q). These indicate that the mixing in the oxidation ditch process is similar to complete mixing. However, the complete mixing model can't be adopted because of the boundary condition of the tank-aeration.

COMPUTER SIMULATION

The change of waste water quality in the oxidation ditch was simulated on the basis of the rate and mixing models indicated above using computer techniques. Kinetic coefficients for the rate models were obtained from the literature²⁾⁻⁴⁾ and related studies by the authors¹⁾. Table 3 presents kinetic and stoichiometric coefficients. Influent waste water quality and other design and operating conditions were assumed as shown in Table 4, by taking into account usual instances.

Also, it was assumed in these simulations that the oxidation ditch consisted of five completely mixed tanks in series with circulation and back-flows, that only the first tank was aerated, and that the excess sludge was not withdrawn from the settling tank.

Based on these assumptions, several factors related to optimum design and

retention time (SRT), the positions of the influent, effluent and aeration, and others were discussed.

Table 3 Kinetic and Stoichiometric Coefficient

U_s (hr^{-1})	0.2	1)-5)	b (-)	0.17	3), 4)
U_1 (hr^{-1})	0.03	1)-5)	c (-)	-	3), 4)
U_2 (hr^{-1})	0.02	1)-5)	d (hr^{-1})	0.002	3), 4)
K_s (mg/l)	100	1)-5)	a' (-)	0.34	3), 4)
K_1 (mg/l)	0.5	1)-5)	b' (-)	4.57	3), 4)
K_2 (mg/l)	0.1	1)-5)	d' (hr^{-1})	0.0008	3), 4)
K_o (mg/l)	0.1	1)-5)	K_{La} (hr^{-1})	2-3	
K_A (mg/l)	100.0	5)	DOs (mg/l)	8.0	
μ (-)	1.14-1.90		e (-)	7.14	
a (-)	0.70	3), 4)	f (-)	3.57	

Table 4 Influent quality and design conditions

Influent	value	Design condition	value
BOD ₅ S_0	200 mg/l	Feed flow Q	$1 Q \text{ m}^3/\text{day}$
NH ₄ -N C_1	50 mg/l	Volume V	$6 \cdot 36 Q \text{ m}^3$
NO _x -N C_2	0 mg/l	Circulate flow I	$100 Q \text{ m}^3/\text{day}$
N ₂ -N C_3	0 mg/l	Return sludge r	$1 Q \text{ m}^3/\text{day}$
Alkalinity A	150 mg/l	MLSS X	3000 mg/l
SS X	0 mg/l	Over all oxygen transfer rate K_{La}	2 hr^{-1}
DO DO	0.01 mg/l		

RESULT AND DISCUSSION

The results of the simulation of the change of water quality in the five tanks in series were shown in Fig.5-10. It is observed that BOD, NH₄-N, and NO_x-N or alkalinity, respectively, increase or decrease little in the flow direction. The oxidation ditch seems to be a completely mixed tank. However, it is noticeable that DO decreases from the first tank aerated to the last tank, especially in the cases of large hydraulic retention times. Figure 11 shows the relationships between the water quality in the last tank and HRT. In the case of DO, the concentration also in the first aerated tank is shown in this figure. The value of BOD decreases with the increase of HRT for this continuous system. The same holds true for the first order reaction as expected for the Monod reaction in the relatively low concentration region. The concentration of NH₄-N is reduced together with alkalinity by nitrification in the region of HRT less than about 20 hours. Beyond this, it increases again because the decrease of alkalinity limits the rate of nitrification, as observed in Japan where the alkalinity of sewage is relatively low. The concentration of NO_x-N increases with HRT to a plateau state. A very low concentration of NO_x-N at a small HRT indicates the occurrence of denitrification, and the high plateau concentration at a large HRT indicates that denitrification as well as nitrification are inhibited, mainly because of the increase of DO and the decrease of alkalinity, respectively. As a result, the concentration of total nitrogen (T-N) as the sum of NH₄-N and NO_x-N decreases and then increases with HRT. To obtain a better understanding, the relationships

between the removal ratios of BOD, NH₄-N and T-N and the hydraulic retention time are shown in Fig.12.

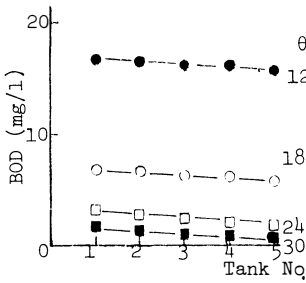


Fig. 5 Change of BOD in tank-in-series model (Retention time θ; hrs)

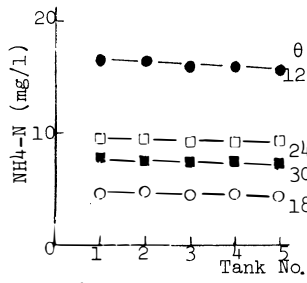


Fig. 6 Change of NH₄-N in tank-in-series model (Retention time θ; hrs)

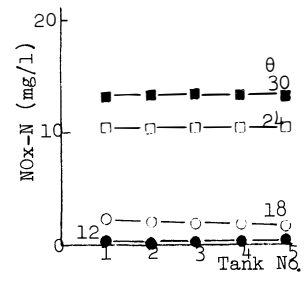


Fig. 7 Change of NO_x-N in tank-in-series model (Retention time θ; hrs)

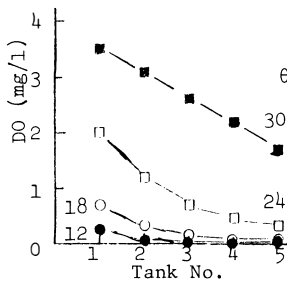


Fig. 8 Change of DO in tank-in-series model (Retention time θ; hrs)

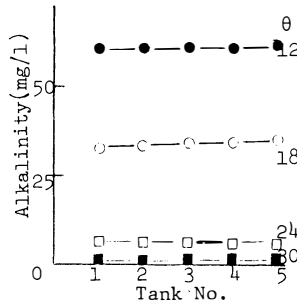


Fig. 9 Change of alkalinity in tank-in-series model (Retention time θ; hrs)

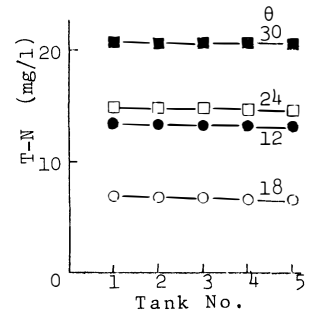


Fig. 10 Change of T-N in tank-in-series model (Retention time θ; hrs)

Based on the above simulation results, several analyses were performed as follows:

(1) Tank volume and other design and operating criteria

The tank volume of an oxidation ditch is usually decided on the basis of empirical HRT, BOD loading or nitrogen loading. By performing simulations as indicated above, however, it is possible to decide the HRT and tank volume so as to ensure the removal efficiencies needed for both BOD and nitrogen. In this simulation, the HRT to maintain both a 90% removal of BOD and 80% for T-N is between 13 and 23 hours, as shown in Fig.11. Using the influent concentrations and these HRT values, the loadings of BOD, BOD·SS, T-N, and T-N·SS are calculated to be 0.23-0.37 kg/m³·day, 0.08-0.12 kg/kg·day, 0.06-0.09 kg/m³·day, and 0.02-0.03 kg/kg·day, respectively. These would be useful indications for practical designs.

(2) Method of aeration

Many kinds of aerators have been recently developed. In order to remove nitrogen as well as BOD, however, any aerator needs to establish such an oxygen distribution decreasing in the flow direction like that for a HRT of 24 or 18 hours as shown in Fig.8. The DO to maintain both the 90% removal of BOD and 80% removal of T-N is estimated to be in the range of 0.3-2 mg/l in the first tank and almost zero in the last tank. Therefore, it isn't efficient to supply excess oxygen and also to use two aerators for nitrogen removal.

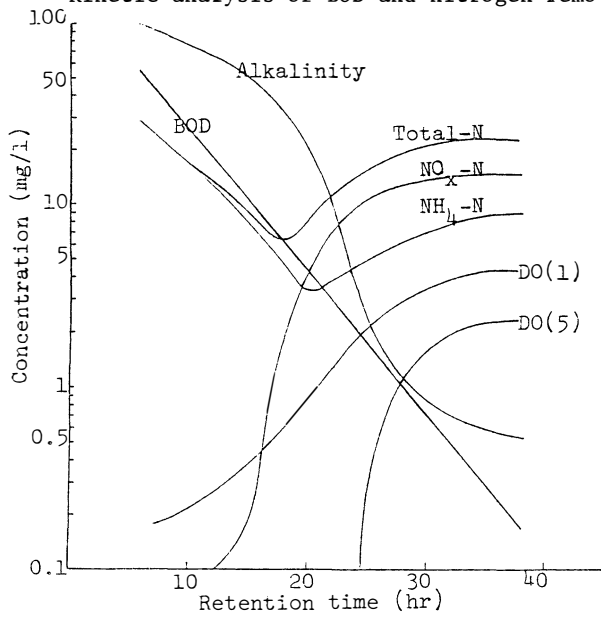


Fig. 11 The relationship between retention time and water quality in the 5th tank. (DO; in the 1st and 5th tanks)

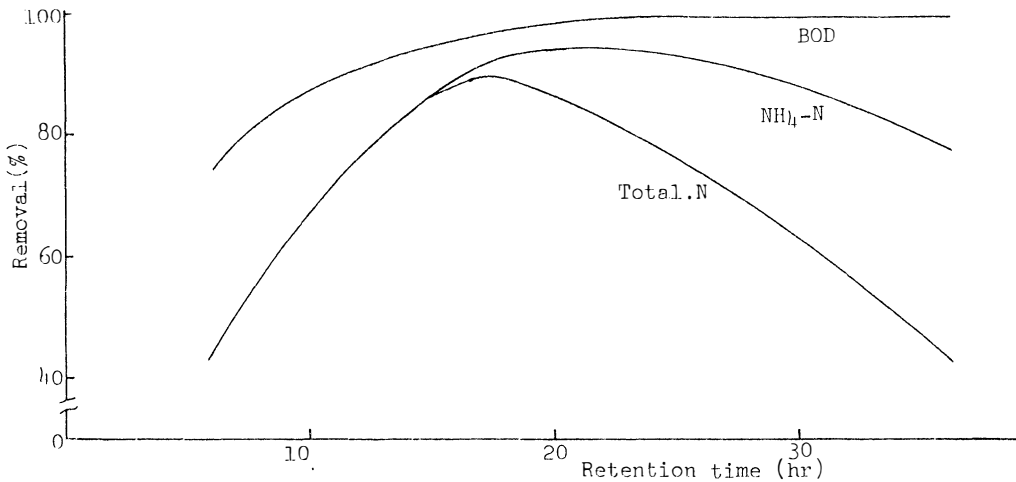


Fig. 12 The relationship between removal (%) and retention time

(3) Effect of alkalinity

The reduction in alkalinity has a large effect on the nitrification of $\text{NH}_4\text{-N}$, and consequently on the denitrification of $\text{NO}_x\text{-N}$. In Fig.10, it can be observed that the alkalinity corresponding to the minimum $\text{NH}_4\text{-N}$ concentration is about 20 mg/l, and that an alkalinity less than 20 mg/l makes the nitrification rate smaller. It is obvious that the alkalinity at any HRT comes from the equilibrium of production and consumption by denitrification and nitrification, respectively.

(4) Positions of influent and effluent

From the above discussions, it seems effective to introduce raw waste water into the ditch at a position which has low DO and high $\text{NO}_x\text{-N}$ concentrations, to

promote denitrification. By an additional simulation, it was shown that the maximum removal ratio of T-N could be improved by 5% when introducing it to the last tank.

(5) Sludge growth rate and sludge retention time (SRT)

The sludge growth rate and SRT are also significant factors in the oxidation ditch process. In this simulation, the calculated values are in the range of 40-70 mg SS/day and 43-70 days, respectively. Such large values of HRT assure enough holding of the nitrifiers without washing out from the ditch.

CONCLUSIONS

The oxidation ditch process can be characterized fundamentally by its inherent simultaneous reactions of organic substrates and nitrogen, and by its flow and mixing patterns. In this work, synthetic kinetic models including the rates of BOD, oxidation, nitrification, denitrification, DO and alkalinity changes, and sludge growth were proposed, mainly based on Monod type kinetics and several limiting effects among these phenomena. Then the tank-in-series model with circulation and back-flow was combined with these kinetic models to form predictive models. The results obtained from computer simulations for the typical design and operating conditions are as follows : (1) Predictive models proposed can reasonably explain the change of waste water quality in the oxidation ditch ; (2) The oxidation ditch can be regarded as an almost completely mixed tank, except for DO ; (3) There is an optimum hydraulic retention time for the removal of $\text{NH}_4\text{-N}$ or T-N ; (4) For the simultaneous removal of BOD and T-N or $\text{NH}_4\text{-N}$, one point aeration would be better to establish the distribution of DO, decreasing to almost zero at the end of the flow. Also the introduction of waste water before aeration is effective ; (5) Alkalinity has a large effect on nitrification. Low alkalinity at a large HRT causes the increase of $\text{NH}_4\text{-N}$ and T-N ; (6) For the assumed treatment requirements of the removal efficiency more than 90 and 80 % respectively for BOD and T-N, the design criteria of HRT was obtained to be 13-23 hours in this study. Also other suggestive design criteria were obtained.

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