Treatability Study on the Septic Tank Sludges

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The characteristics of septic tank sludges were investigated and the kinetic coefficients in the aerobic biodegradation were evaluated from bach treatability tests. Using an unbiased statistical method, the estimated values, k (substrate removal rate coefficient)$=0.0175hr^{-1}$ at 17°C, K_s (Michaelis Menten constant)$=248mg/\ell$, a (cell yield coefficient)$=0.625$, and K_d (cell decay coefficient)$=0.00192hr^{-1}$ were obtained based on biodegradable COD(mg/ℓ) and volatile suspended solids(mg/ℓ). The relationship between COD and BOD, COD $(mg/\ell)=2.1$ BOD$(mg/\ell)+250$, also was established for the septic tank sludges. Dilution was inevitable for the grit removal because of the high viscosity of the sludges. An aerobic activated sludge process rather than anaerobic processes was recommended for the removal of soluble organics after the removal of grit and suspended solids. A multi-stage activated sludge process was adapted for this highly concentrated and not easily-degradable waste. It was estimated that a four-stage activated sludge process would require 40 hours retention time compared to 92 hours for a single-stage process, 52 hours for a double-stage process, and 46 hours for a three stage process in order to achieve an effluent quality of $84mg/\ell$ COD($40mg/\ell$ BOD) with about $4,000mg/\ell$ MLSS from an influent quality of $1,500mg/\ell$ COD($714mg/\ell$ BOD), while multi-stages beyond four stage would not save the required retention time significantly.

INTRODUCTION

Two types of septic tanks are widely used in Korea: one in the cylindrical type which consists of two septic tanks and filter tank, the other in the American style rectangular type with two septic compartments. The cylindrical PVC septic tank is the most commonly used type in Korea. The capacity of a septic tank is regulated by the law: it should be over $0.75m^3$ for up to 15 men served and should be increased by $0.1m^3$ per additional person.

The number of flush toilet in Seoul in 1979 amounted to about 276,300 which is about 40% of the total privy number, 702,600.

Although the septic tank sludges need to be removed once in two or three years if properly designed and operated, the removal frequency set by the law in Korea is once a year to prevent the septic tank from being overloaded. The amount of septic tank sludges collected in Seoul City is expected to be about 200,000 tons in 1979 (40% collection), 481,000 tons in 1986(50% collection), and 788,000 tons in 1991(60% collection) (KIST, 1978).

The reported BOD removal efficiency for septic tanks in Korea ranged from 43% to 47% for 7 member family toilets, while it ranged from 44% to 50% in Japan and the U.S.A. (Min, 1978); thus, the septic tank sludges collected contain a large portion of biodegradable organics, the characteristics of which are expected to vary widely depending on the

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removal frequency and on whether the septic tanks receive domestic wastes or not.

There have not been reported studies about the characteristics and the treatabilities of the septic tank sludges collected in Korea. This study investigated the characteristics and the treatabilities of the septic tank sludges collected in Korea, to seek optimum treatment process for the wastes.

Both aerobic and anaerobic process were employed in screening tests for the treatment. However, it turned out that the septic tank sludges were not easily decomposed anaerobically, naturally because easily degradable portions of organics had already been removed from the sludges while in the septic tanks, and that effluents from anaerobic processes inevitably required aerobic processes to meet the effluent quality requirements, 40*mg/ℓ* BOD, set by the Environmental Preservation Law. Therefore, aerobic processes were chosen for the detailed treatability study.

METHODOLOGY

Ten vehicles were selected at random among the septic tank sludge-collecting vehicles in Seoul for the study of the characteristics of the sludges. The samples were filtered through a No. 30 sieve to remove coarse solids such as papers, rags, plastics, seeds, and grits etc., and were blended for a couple of minutes for homogenization. The analyses for the sludges were performed according to the U.S. Standard Methods (APHA *et al.*, 1971).

For the treatability study, batch removal tests were performed. The activated sludge cultures which had been acclimated to the septic tank sludges were elutriated with tap water and distilled water several times before transferred to 2-liter reactors. The reactors were fed with septic tank sludge filtrates and were filled with distilled water up to 2-liter marks and aerated. The initial MLVSS and COD ranged from 800 to 4,100*mg/ℓ* respectively. The reactors were graduated, and water loss by evaporation was made up with distilled water. Samples were drawn at predetermined time intervals during aeration for the determination of MLSS, MLVSS, filtrate COD, pH, and temperature.

In some reactors, BOD and oxygen consumption rate were measured also. For the oxygen consumption rate measurement, BOD bottles(300 *mℓ*) were filled with mixed liquor samples, and dissolved oxygen changes with time were measured using and dissolved oxygen probe which was designed to seal the BOD bottle during the measurement. A drop of silver nitrate solution(1,000*mg/ℓ* as Ag) was added to samples during filtration except for BOD measurement to inhibit further enzymatic activity and to reduce time measurement error caused by duration of filtration.

RESULTS AND DISCUSSIONS

1. Characteristics of Septic Tank Sludge

The characteristics of septic tank sludge varied with the source, the type of the tank, the sludge retention time, and others. The mean values of the characteristic parameters from 10 samples were as shown in Table 1.

Table 1. Characteristics of Septic Tank Sludge

pH	7.6	T-acidity (*mg/ℓ* as $CaCO_3$)	106
T-COD(*mg/ℓ*)	16,900	T-alkalinity (*mg/ℓ* as $CaCO_3$)	2,200
T-BOD(*mg/ℓ*)	6,420	NH_3-N(*mg/ℓ*)	438
S-COD(*mg/ℓ*)	6,260	NO_3-N (*mg/ℓ*)	3
S-BOD(*mg/ℓ*)	2,970	TKN (*mg/ℓ*)	680
TS (*mg/ℓ*)	18,700	T-P (*mg/ℓ*)	113
VS (*mg/ℓ*)	15,000	Chloride(*mg/ℓ*)	163
FS (*mg/ℓ*)	3,720	Oil and Grease (*mg/ℓ*)	57

As shown in Table 1, the septic tank sludges were better stabilized than night soils and contained oil & grease. The septic tank sludges also contained a large amount of fine sands which probably were the crushed concrete materials or were introduced into the tanks during collection.

2. The Relationship between BOD and COD for Septic Tank Sludge

In the Korean Environmental Preservation Law, the effluent quality requirements for wastewater and night soil treatment plant are specified in terms of BOD. The BOD can easily be estimated by simply measuring the COD, once the relationship between the two parameters is established.

Since some substances can be oxidized chemically but not biologically, the COD is greater than the BOD and a part of COD remains unoxidized after biological treatments. The COD has a linear relationship with the BOD, because the biodegradable COD is proportional to the BOD.

The non-biodegradable COD for the filtrate of the septic tank sludge was evaluated to be $250 mg/\ell$ through batch removal tests with activated sludge, and the relationship between the COD and the BOD was formulated as in equation (1)(See Fig. 1).

$$COD(mg/\ell)=2.1\ BOD(mg/\ell)+250 \quad \cdots\cdots\cdots(1)$$

3. Evaluation of Design Parameters

Monod(1949) developed a model to describe the relationship between the concentration of a limiting nutrient and the growth rate of microorganisms. It is also similar to the Michaelis-Menten relationship used to describe enzyme-catalyzed reaction as follows.

$$\frac{ds}{dt}=\frac{-kXS}{K_s+S} \quad \cdots\cdots\cdots(2)$$

Where,

S : substrate concentration(M/L^3),

t : time(T),

k : substrate removal rate coefficient(T^{-1}),

X : microorganism concentration(M/L^3), and

K_s : Michaelis-Menton constant(M/L^3).

The growth rate of microorganisms closely related to the rate of substrate removal is usually expressed as follows(Heukelekian *et al.*, 1951; stanier *et al.*, 1970).

$$\frac{dx}{dt}=-a\cdot\frac{ds}{dt}-K_dX \quad \cdots\cdots\cdots(3)$$

Where,

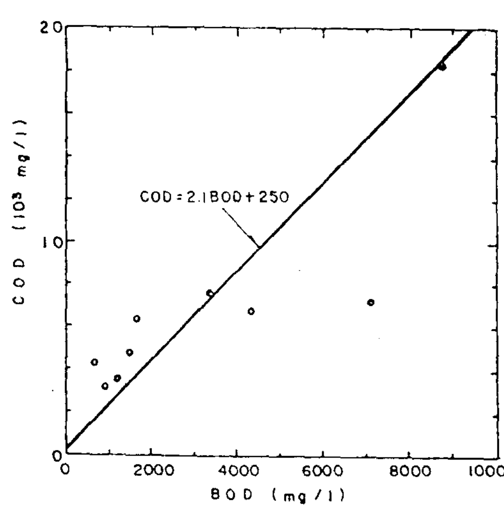

Fig. 1. Relation between COD and BOD in septic tank sludge.

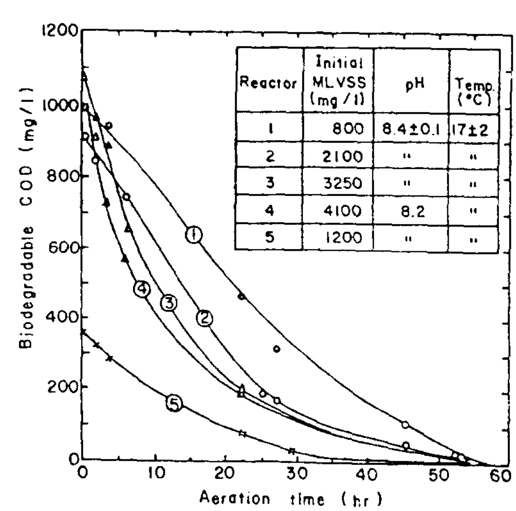

Fig. 2. Efficiency of organic substrate removal in batch test.

a: cell yield coefficient, mass of microorganism/mass of substrate utilized, and

K_d: cell decay coefficient, time^{-1}

The rate of microorganism growth and substrate removal in wastewater would be characterized by the factors, k, K_s, a, and K_d in two equations above.

In this study, the factors were derived from bath tests in laboratory. The biodegradable COD removal rates with aeration time at each reactor are illustrated in Fig. 2.

The design parameters are often estimated using linear graphical methods. However, in this study they were evaluated using computor program developed on the basis of statistical theory(Kim, 1977). The estimated values are listed in Table 2.

Table 2. Estimated Values of Design Parameters

Parameters	Unit	Value	Remark
Substrate removal rate coefficient(k), at 17°C	hr^{-1}	0.0175	substrate concentration: biodegradable COD
Michaelis-Menten Constant(K_s)	mg/ℓ	248	microorganism concentration; MLVSS
Cell yield coefficient(a)		0.625	
Cell decay coefficient(K_d)	hr^{-1}	0.00192	

4. Oxygen Requirement

The oxygen requirement in activated sludge process, which is directly proportional to the amounts of substrate removed and endogenous respiration, could be expressed as the following equation(Eckenfelder and O'Connor, 1961).

$$R_r = -a'\frac{ds}{dt} + b'X \quad \cdots\cdots (4)$$

Where,

R_r: rate of oxygen consumption(mg/ℓ O_2)/time),

a': amount of oxygen required per unit amount of substrate removed(mg/ℓ O_2)/(mg/ℓ substrate),

b': amount of oxygen required for endognous respiration per unit mass of microorganisms (mg/ℓ O_2)/(mg/ℓ biomass/time)

If the equation(4) is devided by X and $\frac{ds}{dt}$ is replaced by $\frac{\Delta s}{\Delta t}$, then the equation (4-a) can be derived.

$$\frac{R_r}{X} = -a'\frac{\Delta s/\Delta t}{X} + b' \quad \cdots\cdots (4\text{-a})$$

If $\frac{R_r}{X}$ is plotted against $\frac{-\Delta s/\Delta t}{X}$, the values of a' and b' are the slope and the y intercept of the graph, respectively.

During the batch test, the oxygen consumption rates in reactor 2, 3, and 4 (See Fig. 2) were measured and the results are illustrated in Fig. 3. From Fig. 3, the values of a' and b' were estimated to be 0.38 and 0.003hr^{-1} respectively.

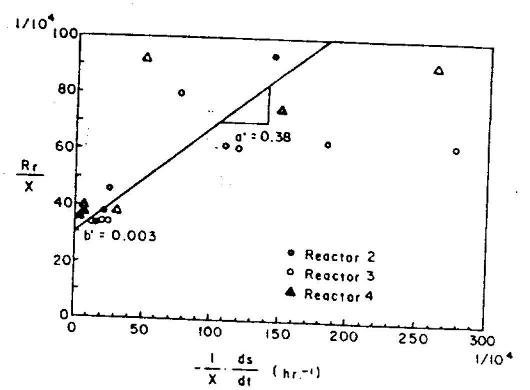

Fig. 3. Evaluation of a' and b' value. (septic tank sludge)

5. Optimization of Activated Sludge Process for Septic Tanks Sludge

As the septic tanks sludge had considerable amount of fine sands, it was necessary to dilute it at least 4 times at a screen chamber for the removal of the fine sands. Otherwise, they would not settle down in a grit chamber due to high viscosity. Except this, the physical and chemical treatments of septic tank sludge before and after aeration tank are the same as those of a normal wastewater treatment plant. Therefore, main efforts were made on the optimization of aeration process because the decomposition of the organic substrate in septic tank sludge was rather difficult compared to organic substrates in normal wastewater. Since suspended solids could be removed in primary treatment, the substrate concentration of influent for aeration tank was estimated to be the soluble COD. The biodegradable COD of the influent was 1,500mg/ℓ.

[6,260mg/ℓ(filtrate COD)$-$250mg/ℓ(non-biodegradable COD)]$\times\frac{1}{4}$(dilution factor)$=$1,500 mg/ℓ. In Korean Environmental Preservation Law, the effluent concentration of BOD from a night soil treatment plant is 40mg/ℓ, which is equivalent to 84mg/ℓ of biodegradable COD. Now what to be found is the optimum process to reduce 1,500mg/ℓ of biodegradable COD to 84mg/ℓ under the condition with the kinetic coefficient values estimated in this study.

In general, the activated sludge process in complete-mixed system can be illustrated as in Fig. 4.

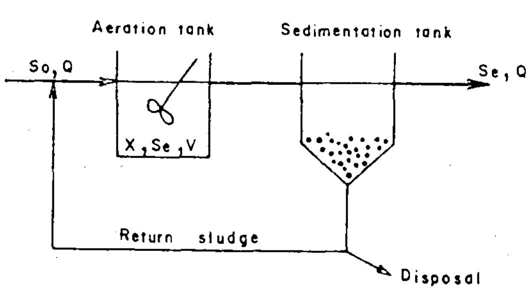

Fig. 4. Schematic diagram of activated sludge process unit.

The substrate removal rate in aeration tank can be expressed as follows.

$$V\frac{ds}{dt}=QS_0-QS_e-\frac{kXS_eV}{K_s+S_e} \cdots\cdots (5)$$

Where,

Q: flow(m^3/day)

V: volume of aeration tank(m^3)

S_0: influent concentration(mg/ℓ)

S_e: effluent concentration(mg/ℓ), and

X: MLVSS(mg/ℓ)

At a steady state, $\frac{ds}{dt}=0$; thus,

$$QS_0-QS_e-\frac{kXS_eV}{K_s+S_e}=0 \cdots\cdots (5\text{-a})$$

If the equation is rearranged to solve for S_e, then

$$S_e=\frac{-(TkX+K_s-S_0)+\sqrt{(TkX+K_s-S_0)^2+4K_sS_0}}{2} \cdots\cdots (5\text{-b})$$

Where, $T=\frac{V}{Q}$(detention time).

Now it is possible from equation (5-b) to evaluated the detention time to meet effluent standard under the following condition.

$S_0=1,500mg/\ell$

$K_s=248mg/\ell$

$X=4,000mg/\ell$

$S_e=84mg/\ell$

$k=0.0151hr^{-1}$

The k value was calibrated for the temperature 7°C which was the lowest temperature expected for the treatment system in winter as follows.

$k_{7°C}=k_{17°C}\theta^{(7-17)}$ ($\theta=1.015$, $k_{17°C}=0.0175$)

Here, it can be noticed that the detention time required for the treatment of septic tank sludge is about 93 hours, which requires quite a lot of space and money for the treatment plant construction. This result is not welcomed in Korea because the land even in the countryside near Seoul is very expensive. Therefore, efforts to reduce the required space were made by comparing single stage with mult-stage aeration process. In mult-stage aeration tank (Fig. 5), the effluent and microorganism concentration at i th stage can be calculated using the equation (6) and (7).

$$S_i=\frac{-TkX_i+K_s-S_{i-1})+\sqrt{(TkX_i+K_s-S_{i-1})^2+4K_sS_{i-1}}}{2} \cdots\cdots (6)$$

$$X_i=X_{i-1}-a(S_i-S_{i-1})-K_dX_iT \cdots\cdots (7)$$

By using equation (6) and (7) iteratively, it is possible to evaluate the relationship between effluent concentration and detention time for multi-stage process, as demonstrated in Fig. 6.

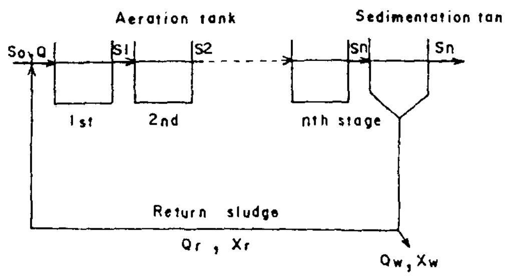

Fig. 5. Diagram of multi-stage activated sludge process.

From Fig. 6, it can easily be noticed that the required detention time to meet effluent standard of 84*mg/ℓ* is 93 hours for single-stage, 52 hours for double-stage, 46 hours for three-stage and 40 hours for four-stage process. It was found that the degree of reduction in detention time at more than four stages was negligible.

Therefore, the four-stage aeration system

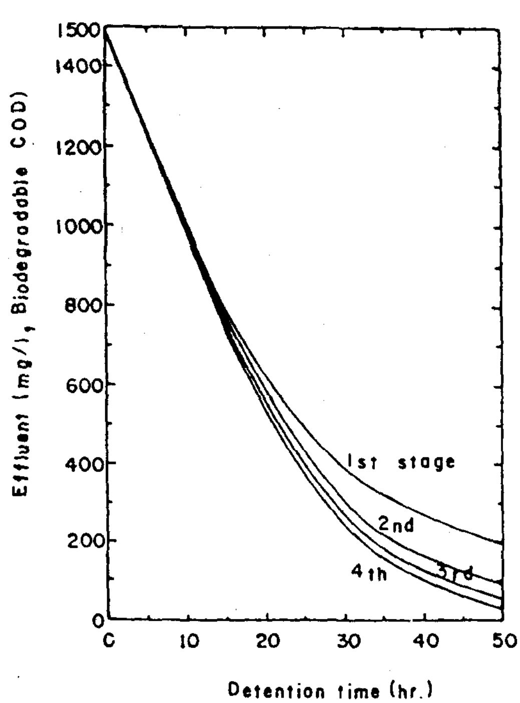

Fig. 6. Relationship between effluent concentration and detention time at each stage.

was considered to be one of the most effective methods for the treatment of septic tank sludge in Korea.

The concentrations of MLVSS and COD at each stage of four-stage system with the total detention time of 40 hours are tabulated in Table 3.

Table 3. Influent, Effluent, and MLVSS Concentration of Each Stage at the Four Stage Process

Stage	Influent concentration (*mg/ℓ*)	Effluent concentration (*mg/ℓ*)	MLV-SS (*mg/ℓ*)	Detention time (*hr*)
1	1,500	1,015	4,000	10
2	1,050	572	4,200	10
3	572	248	4,300	10
4	248	84	4,300	10

Finally, a comparision between one-and four-stage process in the light of detention time and required aeration tank volume is tabulated in Table 4.

Table 4. Comparision between One and Four-Stage Process in the View of Detention Time and Aeration Tank Volume

One-Stage	Four-Stage
$\frac{V_1}{Q}=\frac{(248+84)\ (1,500-84)}{0.015\times 24\times 4,000\times 84}$ $=3.86\text{day}(=93hrs)$	$\frac{V_4}{Q}=1.67\text{day}(=40hrs)$
$V_1=3.86Q$	$V_4=1.67Q$

Detention time; $\frac{V_1}{Q}-\frac{V_4}{Q}=2.19\text{day}(=53hrs)$

Volume; $\frac{V_4}{V_1}=3.86Q/1.67Q=2.3$

* V_1; Volume of aeration tank for one-stage system, V_4; Total volume of aeration tank for four-stage system.

As shown in Table 4, the four-stage activated sludge system saves 53 hours of retention time, or reduces the volume of aeration basin to about 43 percent, compared to the single-stage system.

CONCLUSIONS

From the treatability study on the septic tank sludges, the following results were obtained.

1. The characteristics of the septic tank sludges depended on the efficiencies of the septic tanks, the periods of storage, and others; however, the average values, COD was 16,900 mg/ℓ, soluble COD was 6,260mg/ℓ, BOD was 6,420mg/ℓ, and soluble BOD was 2,970mg/ℓ.

2. Using a statstical method, the substrate removal rate coefficient(k), Michaelis-Menten constant(K_s), cell yield coefficient (a), and cell decay coefficient(K_d) were estimated to be 0.0175hr^{-1}(at 17°C), 248mg/ℓ, 0.625, and 0.00192hr^{-1}, respectively from batch tests, based on the biodegradable COD(mg/ℓ) and the MLVSS(mg/ℓ).

3. Through a linear graphical method, the oxygen requirement per substarte utilized(a') and the oxygen requirement per biomass for endogenous respiration(b') were estimated to be 0.38 and 0.003hr^{-1}, respectively.

4. The detention time required to achieve an effluent quality of 40mg/ℓ BOD was 93 hours for single-stage, 52 hours for double-stage, 46 hours for three-stage, and 40 hours for four-stage activated sludge process with about 4,000mg/ℓ of MLVSS in aeration tank; the four-stage process could save 53 hours of aeration time or 43 percent of the aeration tank volume compared to the single-stage process.

5. Multi stages beyond four stages did not save the required detention time significantly; thus, the four-stage activated sludge process was regarded as the optimum process for treating the septic tank sludges in Korea.

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