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HIGH PERFORMANCE AND N & P-REMOVABLE ON-SITE DOMESTIC WASTE WATER TREATMENT SYSTEM BY MULTI-SOIL-LAYERING METHOD

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ABSTRACT

Multi-Soil-Layering (MSL) method was applied to make appropriate, but high performance and N & P-removable, on-site domestic waste water treatment system. The MSL soil unit is composed from soil layer mixed with 10~25% of metal iron and pelletized jute. The MSL units were piled in a brick pattern at 5cm vertical and 10cm horizontal distance, which were surrounded by layers of Zeolite. Air can be supplied through porous pipes installed at adequate depths of the MSL system. The systems were tested using model houses. The waste waters, which were pretreated by septic tank to the level of SS 29-75, BOD 42-116, COD 32-56, T-N 29-86, and T-P 6-11 $mg \cdot l^{-1}$ respectively, could be treated at the rate of 100-850 $l \cdot m^{-2} \cdot d^{-1}$ without significant clogging. The mean concentrations of treated waters were SS 15, BOD 8.7, COD 11, T-N 6.8, and T-P 0.86 $mg \cdot l^{-1}$ respectively. Zeolite layers and brick pattern prevent clogging. Metal iron and jute pellets were effective to remove Phosphate and Nitrate. Intensive aeration assists decomposition of BOD, COD, and SS as well as nitrification, but decreases denitrification and phosphate fixation. The degree of purification could be controlled by setting adequate aeration.

KEYWORDS

Domestic waste water, Jute pellet, Metal iron, MSL system, Nitrogen, Onsite system, Phosphorus, Septic tank, Soil system, Zeolite

INTRODUCTION

Pedosphere is a center for Carbon, Nitrogen, and Phosphorus cyclings in terrestrial ecosystems. Soils have powerful functions to decompose and mineralize organic matter. Traditional septic systems are using the functions of soils (Moukan-Jouka-Kenkyukai 1983, Suzuki et al. 1983, Bhamidimarri 1988, Kaplan 1988, Perkins 1989, Suzuki & Yamaura 1989, Kawanishi et al.1990). Although septic tank systems are widely used in rural-residential areas for on-site disposal of household and institutional wastewaters, there have been limited researches to improve the functions of soils in the system.

In traditional soil systems, the aggregate structure of soil is the key to purify waste water. The specific surface area of aggregates is more than 1-10m². Therefore aerobic surfaces of aggregates can decompose organic matter and nitrify efficiently. But the inside of aggregates is in anaerobic condition, where denitrification is possible, if adequate carbon sources coexist. Major components of clay minerals which form the aggregates are hydroxy oxides of aluminium and iron. Phosphates in waste water can be fixed by these hydroxy oxides.

Soils, however, have various problems in waste water treatments. The most serious problem is clogging. The clogging which is caused by deposition of dispersed clay particles in pore spaces of soils is difficult to overcome whereas, the problem of clogging by organic matter can be met by alternate use at adequate intervals. But long-term acceptance rate of waste water in leach line of traditional septic tank system was only 50 $l \cdot m^{-2} \cdot d^{-1}$ as long as it depends on only natural soil body. Thus leach field requires a wide area.

Long term leaching of sodium-rich waste water makes soil clays into sodium saturated type, which is easy to disperse and clog. Addition of calcium in waste water or mixing of calcium carbonate may be effective to prevent clay dispersion. In Multi-Soil-Layering (MSL) method, brick pattern of soil and zeolite layers, as shown in Figures 1 and 2, prevents formation of impermeable layer. Long term experiments showed that zeolite was also effective to prevent sodium saturation of clay in MSL system.

The short-circuit of waste water is another problem in leach field of septic tank systems. The short-circuited waste water can not be purified. To solve this problem, MSL has permeable zeolite layers arranged in brick pattern, which makes waste water distribute widely and therefore have good contact with soil layers for effective treatment.

Traditional septic tank system can not remove nitrate effectively. The leached nitrate is polluting ground water(Kaplan 1988, Perkins 1989). Although aerobic soil aggregates have effective for nitrification, enough anaerobic sites cannot coexist with the aerobic sites. Furthermore, carbon sources are decomposed in coupling with nitrification. This makes denitrification difficult in traditional soil systems. In MSL system, pelletized jute was added as carbon source for denitrification.

The capacity of phosphate absorption of soils differs widely. Some Andisols can fix phosphate-P up to 1g per 1kg, whereas quartz-rich sandy soils can fix only 0.1g per 1kg. The mixing of metal iron particles in MSL system improves the phosphate fixing capacity of soil dramatically. The addition of 10 weight percentages of the metal iron increases the phosphate-P fixing capacity up to 5-10g, or more, per 1kg of soil.

The MSL method can solve various problems in traditional septic tank and leach line systems. The results of the basic research of the MSL method were reported (Wakatsuki el al. 1989, 1990, 1991). We describe here the interim results of two demonstration systems of the MSL methods tested at two model houses during March 1990 to July 1991.

DESCRIPTION OF TWO MODEL MSL SYSTEMS

Figure 1 shows the structure of a fixed loading type of MSL system tested at a model family living in Kurume city, northern Kyushyu, Japan. The two bigger concrete boxes, A and B, 2000×1200×1600mm, are for alternate use. One smaller concrete box is for pumping up of waste water into the system in a fixed loading rate as shown in Figure 3. Another smaller concrete box is for pumping up of treated water.

As shown in the perspective figure of A, two sets of porous pipes with 75mm diameter for waste water infiltration and two sets of porous pipes with 16mm diameter for aeration were installed at 15 & 70cm and 65 & 128cm depths, respectively. Mean daily waste water inflow rate was estimated as 1500 l, which was equivalent to 625 $l \cdot m^{-2} \cdot d^{-1}$ acceptance rate. This loading rate is more than ten times higher than that in the leach field of traditional septic tank system.

The cross section of Figure 1 shows the detailed structure and arrangement of MSL. Let's see the structure from bottom to top. The bottom 10cm, in which a drainage pipe with 10cm diameter was installed, was filled with the gravels. The surface of the gravel layer was covered with plastic net to protect dropping out of soil particles. Then, three wooden frames, 75×100×1200mm, were put on the plastic net parallel at the distances of 25 and 95cm from both side walls. Clinoptiolite type of zeolite with diameter of 5mm was filled up in the wooden frames. In the spaces between frames and walls, clay loam soil was filled up to 75cm depth. After removing the wooden frames,the lowest layer was covered with 5cm depth of zeolite layer. The next layer was filled up in the similar way, but shifted by 35 cm to the lowest layer. Next layer was again covered with 5cm depth of zeolite layer, in which aeration pipe was installed. The other layers were also filled up in the similar pattern, but soils in the next four layers were filled after mixing 15% of pelletized jute and 15% of metal iron particles of 10mesh size. The iron, jute, and soil mixtures were put in the jute bags for convenience of filling up. Four black circles in the cross section show the points of ceramic cups for collection of soil solution. Between 5th and 6th layer, porous pipe for waste water infilitration was installed in gravel layer. This porous pipe in lower depth was used for diversion of inflow of waste water to assist denitrification. However, during the present experiment this pipe was not used. After filling up 6th layer, upper aeration pipe was installed. Next two soil layers were filled after mixing 5% of metal iron. The method for filling up was same as that of the lowest two layers. The upper porous pipe for waste water inflow was installed in gravel layer between 15 and 35cm depth. Finally the whole MSL system was covered with topsoil.

This system was tested during 1 March 1990 to 31 July 1991 and the testing is continuing. During this period, only part A was used for treatment. No clogging was observed.
Figure 2 shows another MSL system tested using a family living in Matsue city, western Japan. The waste water inflow and treated water outflow were driven by natural slope. Except for the method of inflow and outflow, the structure and arrangement are essentially the same as those of former system (Figure 1). Major differences are as follows. The system occupied wider area and shorter depth than those of the former one. Particle size of zeolite was 1~3mm. Soil was sandy of granite origin. To

the soil, 15% metal iron and 10% pelletized jute were mixed as well as mixing 15% of litter to assist microbiological activity. One aeration pipe and one waste water infiltration pipe were installed respectively.

The A, B1, and B2 were for testing adequate alternate use. Planned loading rate was 250 $l \cdot m^{-2} \cdot d^{-1}$ for A and 500 $l \cdot m^{-2} \cdot d^{-1}$ for B1 & B2. However the actual loading rate was half of that planned as shown in Table 1. This report described the results during 25 July 1990 to 24 July 1991. Although only part A was used during this period, no serious clogging was observed.

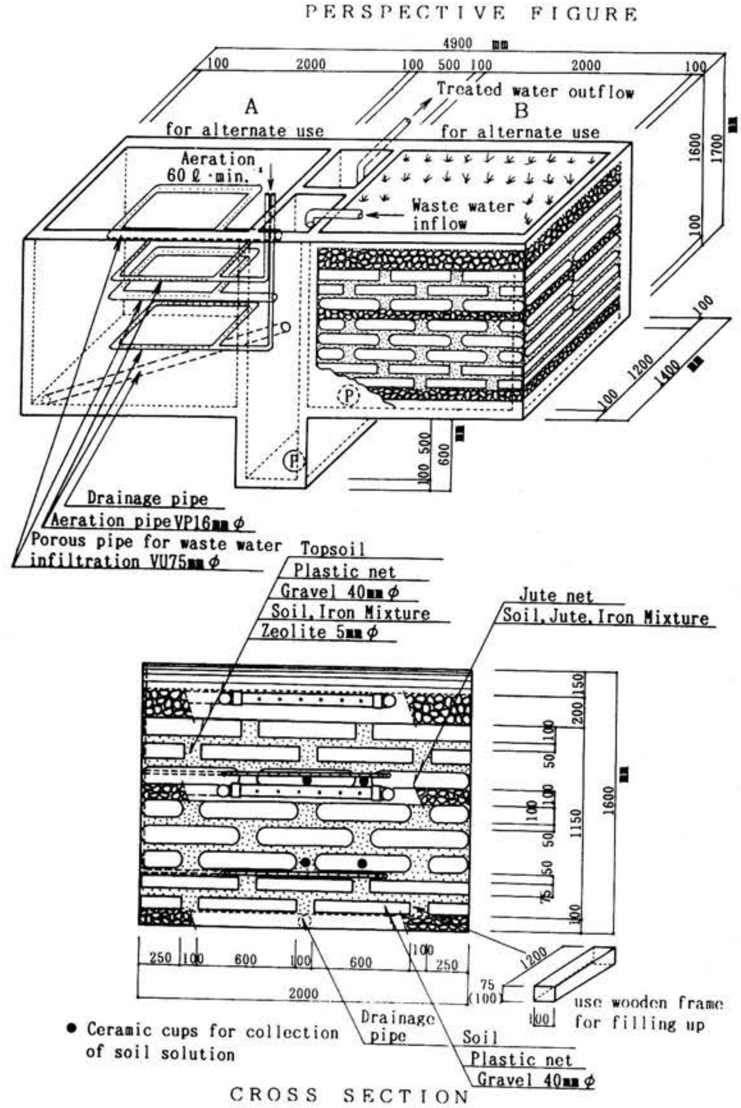
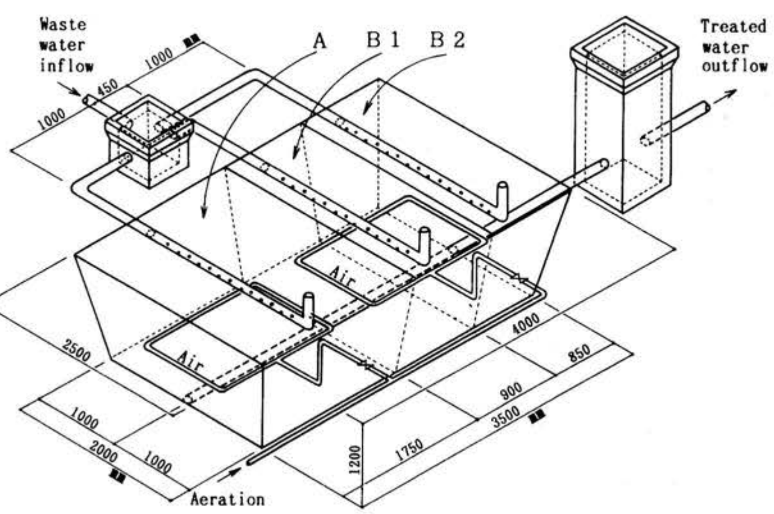
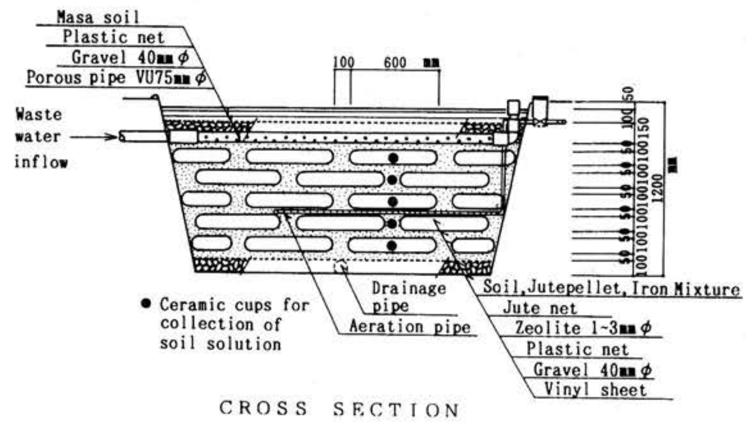


Figure 1. Structure of fixed loading type of model Multi-Soil-Layering System, tested at Kurume city, Japan.

PERSPECTIVE FIGURE





CROSS SECTION

Figure 2. Structure of Natural Inflow Type of Model Multi-Soil-Layering System, tested at Matsue City, Japan.

RESULTS AND DISCUSSION

1. Hourly Fluctuations of Characteristics of Waste and treated water

Figure 3 shows the results of system tested at Kurume city (Figure 1). Hourly fluctuations of concentrations of COD, T-P, and T-N in treated waters (Upper), hourly waste water inflow rate (Middle), and hourly treated water outflow rate (Lower) are shown. Mean concentrations of waste water in survey period from 16:00 on 14 November to 16:00 on 15 November were 28.4 $mg \cdot l^{-1}$ for COD, 30.1 $mg \cdot l^{-1}$ for T-N and 2.85 $mg \cdot l^{-1}$ for T-P, respectively. Since the inflow rate was controlled by pump the outflow rate was almost constant. Although the loading rate was very high, 850 $l \cdot m^{-2} \cdot d^{-1}$, T-N, COD and T-P were purified efficiently

Figure 4 shows the results of the system at Matsue city (Figure 2). Since the input rate was not controlled, fluctuation was extremely high. More than 80% of total waste water inflow happened during 18:00-22:00. The peak time of outflow was 21:00−24:00. The efficiency of P and N removal was, however, very high: T-N was reduced from 78.4 to less than 5 $mg \cdot l^{-1}$, T-P was 12.5 to less than 1 $mg \cdot l^{-1}$. But, COD removal was not so high. While the system of Figure 1 (results were shown in Figure 3) continued aeration for 24hr, time of aeration was only 0.5hr per day in the system of Figure 2 (results are shown in Figure 4) during this survey period.

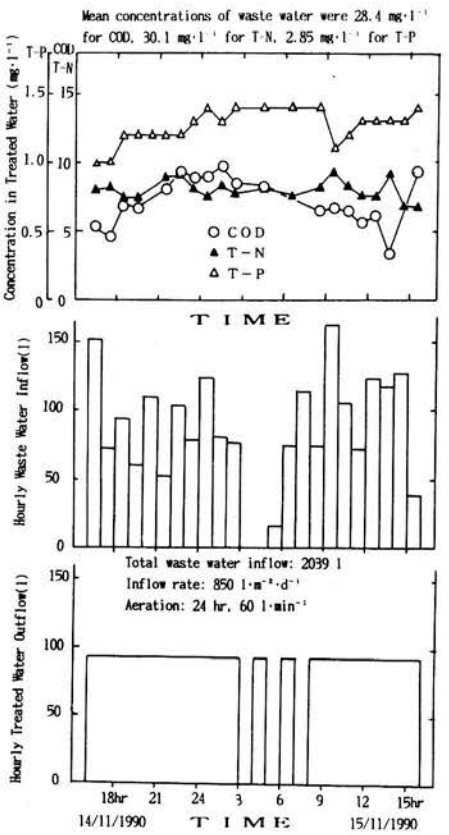


Figure 3. Hourly Fluctuations of Waste and Treated water Characteristics in Fixed Loading Type MSL System

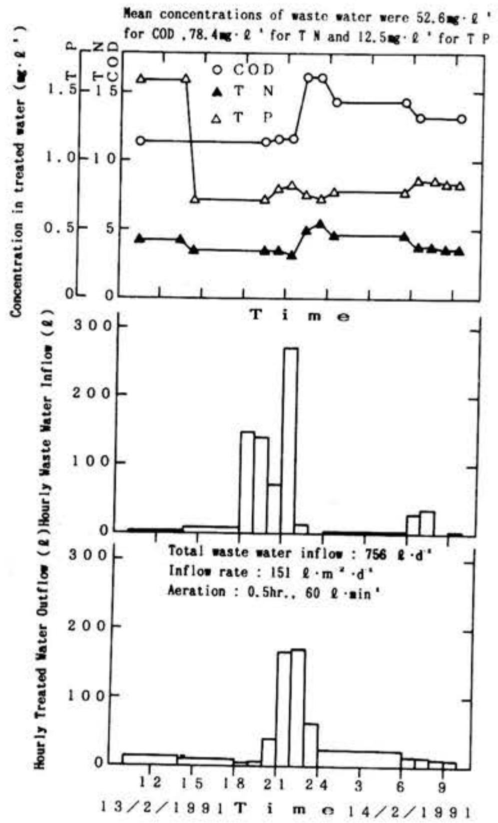


Figure 4. Hourly Fluctuations of Waste and Treated Water Characteristics in Natural Inflow Type MSL System

2. Seasonal fluctuations of quality of waste and treated water

The results obtained from the system in Matsue city (Figure 2) during 25 July 1990 to 24 July 1991 are shown in Table 1. During this period samples were collected and analyzed every week. Depending on the quality of treated water, aeration time was changed. Table 1 shows the mean values at each sub-period which had same aeration time.

The range of mean air temperatures at each sub-period was 4.9-24.6°C. The range of mean precipitations was equivalent to 4.1-7.7 $l \cdot m^{-2} \cdot d^{-1}$. The waste water showed a wide range of fluctuations of SS 11.1-74.8, BOD 41.8- 116.0, COD 32.2-55.7, NH_4-N + Org-N 17.2-77.9, NO_2-N + NO_3-N 0.2-18.4, T-N 28.6-86.3, and T-P 6.0-10.5 $mg \cdot l^{-1}$, respectively. The treated waters had the following ranges of quality: SS 4.0-45.9, BOD 2.4-23.0, COD 8.8-19.2, NH_4-N +Org-N 1.5-7.2, NO_2-N +NO_3-N 0.5-8.1, T-N 3.2-14.5, and T-P 0.3-2.0 $mg \cdot l^{-1}$, respectively.

The quality of treated water was influenced significantly by aeration. The results were obtained in rather preliminary setting of aeration. Therefore, if we could set more adequate aeration in each sub-period, the results would improve further.

Table 1. Summary of results of domestic waste water treatment tested at Matsue city, during 25 July 1990 to 24 July 1991.

Period of Survey	25/7 20/9	21/9 31/10	1/11 29/12	30/12 30/1	31/1 15/2	16/2 30/3	31/3 17/4	18/4 24/5	25/5 24/7
Air temp.(°C)	24.6	18.0	10.4	4.9	5.2	7.0	12.5	17.8	23.0
Precipitation($l \cdot m^{-2} d^{-1}$)	6.1	4.4	4.7	5.4	5.4	4.1	4.3	4.1	7.7
Loading rate($l \cdot m^{-2} d^{-1}$)	146	116	128	136	126	110	134	148	134
Aeration time($hr \cdot d^{-1}$)*	**24**	**6**	**0**	**2**	**0.5**	**1**	**2**	**24**	**12**
SS Waste water($mg \cdot l^{-1}$)	29.1	34.4	47.7	60.0	61.3	60.1	74.8	35.1	40.4
Treated water(〃)	5.3	5.3	21.9	4.0	13.6	25.4	35.9	11.1	15.6
BOD Waste water (〃)	45.7	52.4	53.8	79.8	41.8	71.3	116.0	44.6	45.6
Treated water(〃)	2.6	2.4	7.7	3.7	6.1	12.9	23.0	10.5	16.2
COD Waste water (〃)	32.3	40.8	45.7	47.2	39.9	42.6	55.7	47.5	37.4
Treated water (〃)	11.6	9.0	11.8	8.8	9.7	15.3	19.2	10.8	11.2
NH_4-N + Org-N Waste water (〃)	17.2	58.4	27.8	63.0	77.9	51.5	72.0	67.9	49.2
Treated water(〃)	2.2	1.5	2.7	2.3	2.1	3.9	7.2	3.6	6.5
NO_2-N + NO_3-N Waste water (〃)	11.4	8.6	10.8	6.0	5.3	1.3	0.2	18.4	21.0
Treated water(〃)	2.2	6.5	0.5	3.5	1.9	1.4	0.9	6.2	8.1
T-N Waste water (〃)	28.6	67.0	38.6	69.0	83.2	52.8	72.2	86.3	70.2
Treated water(〃)	4.4	8.0	3.2	5.8	4.0	5.3	8.1	9.8	14.5
T-P Waste water (〃)	7.3	9.1	9.4	7.0	6.7	6.0	6.0	9.4	10.5
Treated water(〃)	0.3	2.0	0.6	0.6	0.5	1.4	1.6	0.6	1.1

*rate of aeration was 60 $l \cdot min^{-1}$

3. The Relation Between Aeration and Efficiency of Treatment

Figure 5 shows the relation between aeration time and concentrations of BOD, SS, TIN (NO_3-N + NO_2-N + NH_4-N), and PO_4-P in treated water in the system of Figure 2. The unit rate of aeration was 60 $l \cdot min^{-1}$. The efficiency of N and P removal was in inverse correlation with aeration time, but the efficiency of removal of BOD and SS was in direct correlation with aeration time.

Figure 6 shows the relation between aeration time and concentrations of Fe, NO_3-N, NH_4-N, and PO_4-P in soil solutions at various depth in cm in the system of Figure 2(sampling points are shown as black circles). At no aeration , NH_4-N was detected in the soil solution collected at 55 cm depth, but NO_3-N was not detected in the whole soil depth. Similarly, PO_4-P was detected only at the top 25cm depth. On the other hand, at 6 hr aeration , NH_4-N was detected only at 25 cm, but NO_3-N and PO_4-P were detected in the whole soil depth. At the 2 hr aeration, results were intermediate. The results in Figures 5 and 6 show that aeration has strong effects on the efficiency of treatment. Since these results were obtained at winter season, the best aeration time for treatment may be longer in summer season.

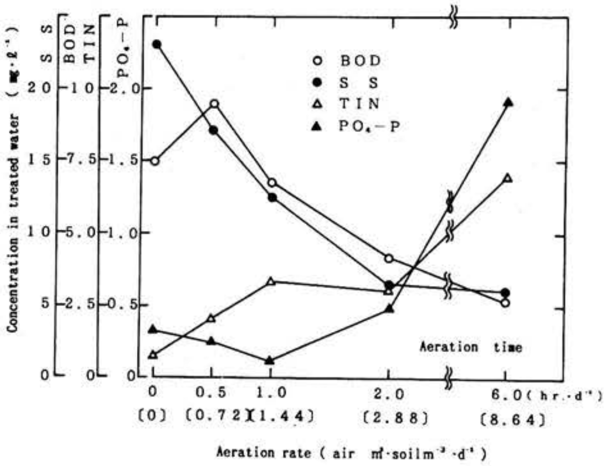


Figure 5. Relation Between Aeration Time and Efficiency of Treatment
(survey period: October 1990-February 1991)

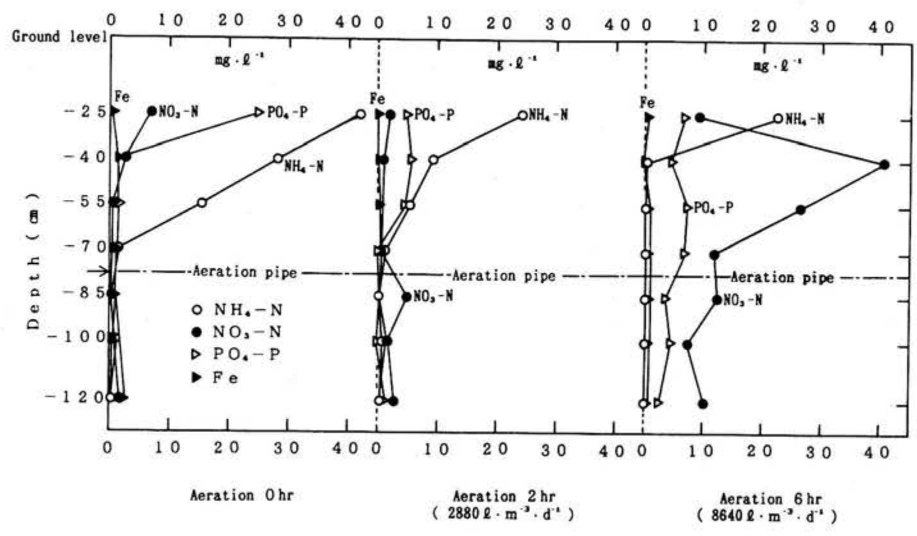


Figure 6. Relation Between Aeration Time and Dynamics of Soil Solution at Various Depths in System of Figure 2
(survey period: October 1990-January 1991)

4. Possible mechanisms of purification in the MSL system

Figure 7 shows possible mechanisms of purification of waste water in MSL system. Organic matters are decomposed on aerobic parts of the layers, such as gravels and zeolite, and at the interface between zeolite and soil layers. Nitrification may proceed in coupling with organic matter decomposition. Some ammonium ions are fixed in zeolite which make longer residence time. Zeolite works not only for efficient infiltration and distribution of waste water but also for buffering pH change during treatment. Metal iron in soil is oxidized to ferrous ion, which is transfered to zeolite layers and oxidized further to ferric ion and deposited on the zeolite particles as hydroxides which can fix phosphate ion. Pelletized jute is used for denitrification in anaerobic parts of soil layers. Oxidation of jute and metal iron contributes to produce anaerobic conditions. Adequate aeration assists to supply oxygen to the aerobic parts in the system. But excessive aeration makes the whole MSL system aerobic, which therefore brings poor denitrification and phosphate removal.

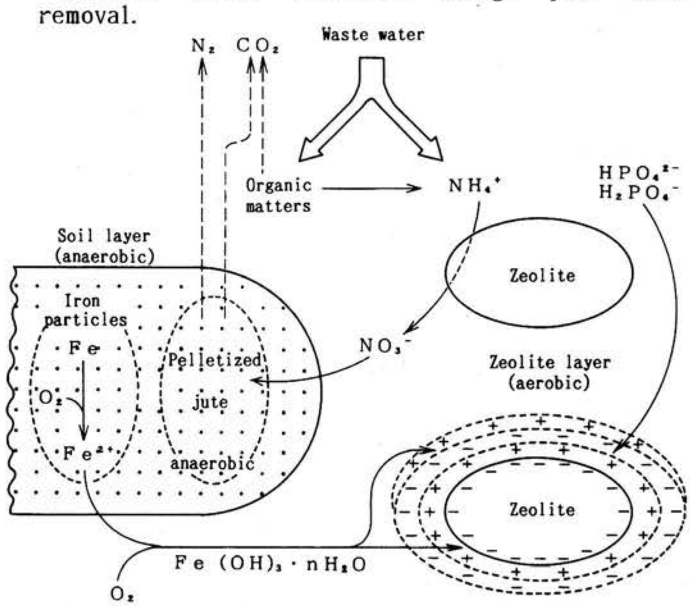


Figure 7. Possible Mechanisms of Purification Operating in MSL System

5. The life of Iron Particles and Pelletized Jute for N and P Removal

The amount of carbon of jute used in the system was about 150 kg. If we assume the carbon nitrogen ratio for denitrification is 1, then 150kg of NO_3-N can be removed. If we assume that the amount of daily waste water is 1000 l, T-N concentration is 40 $mg \cdot l^{-1}$, and 80% of T-N is removed using the carbon in jute, then daily rate of NO_3-N removal becomes 32g. This gave the life of jute for denitrification as 12.8 years.Actual life may be longer or shorter than this estimate. If the carbon from waste water is used for denitrification, life will be longer. If the jute is decomposed in uncoupling with denitrification, life will be shorter.

Stoichiometry shows 1 mole of iron can fix 1 mole of phosphate.However the efficiency of iron in the system is unknown. If we can assume the efficiency is 15%, metal iron mixed in MSL system can fix 25kg of PO_4-P. If the system removes 90% of 6.5 $mg \cdot l^{-1}$ of PO_4-P in 1000 l of waste water every day, the life of the metal iron in the system becomes 11.7 years. The life may change depending on the amounts of mixing and operating conditions, too. Therefore longer testing is necessary.

CONCLUSION

Soil resource will be more important for future waste water treatment. Because it will be a more urgent matter to regenerate the material recyclings for sustainable management of our environment. The MSL system explained here cannot only purify waste water but also produces fertile soil during the treatment. The soil and zeolite can be recycled in agricultural land to improve soil fertility after purification efficiency is over.

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