ABSTRACT

A multi-soil-layering (MSL) wastewater treatment system has been operating in Matsue city, Japan for some time. Recently, a MSL system has come into operation in Bangkok, Thailand. This Bulletin examines the efficiency of the system in purifying wastewater in a temperate and a tropical climate, respectively.

The MSL system consists of a soil mixture placed in a tank in blocks with alternate layers of zeolite. The components of the soil mixture vary according to local resources, but include iron pellets or iron scraps. Pre-treated wastewater is discharged into the MSL system, fed by gravity.

Aerobic conditions occur in the zeolite, and anaerobic conditions in the saturated soil blocks. This mixture of aerobic and anaerobic conditions allows for the efficient purification of wastewater. Nitrogen is removed by both (aerobic) nitrification, and reduction under anaerobic conditions. Phosphate is removed by forming insoluble compounds.

Results showed that the MSL system is an efficient way of purifying wastewater in both a temperate and a tropical climate. The rate and duration of aeration are key factors in increasing the effectiveness of the MSL system. In the temperate climate of Japan, aeration was particularly important during the winter. In the warm climate of Thailand, the system worked best when one month with aeration was alternated with two months without aeration throughout the year.

INTRODUCTION

A multi-soil-layering (MSL) system enhances the inherent ability of the soil to purify wastewater (Wakatsuki et al. 1993). A MSL system generally consists of blocks of soil mixture, alternated with zeolite inter-layers in a brick-like pattern. (Note: zeolite is a highly porous crystalline substance).

The MSL system can be separated into two zones, aerobic and anaerobic. Aerobic conditions occur in the zeolite inter-layer, which has a high proportion of coarse pore spaces. The soil mixture has a high adsorption capacity and is saturated with the wastewater. As a result, anaerobic conditions develop.

The efficiency of the MSL system in purifying wastewater basically depends on the relative distribution of aerobic and anaerobic
conditions (Attanandana et al. 2000; Wakatsuki et al. 2000). Aerobic conditions enhance nitrification, the decomposition of organic matter, and the oxidation of ferrous iron to ferric iron, facilitating phosphorus sorption. In the anaerobic zone of the soil mixture, however, nitrate is transformed into nitrous oxide and nitrogen gas (Wakatsuki et al. 1993).

If the MSL system is used continuously without some kind of aeration, anaerobic conditions become dominant. Strong anaerobic conditions reduce the efficiency of the MSL system in removing organic substances, nitrogen, and phosphorus (Luanmanee et al. 2001). Therefore, aeration is essential to enhance the effectiveness of the MSL system for wastewater treatment.

Aeration of the MSL system can enhance the biochemical oxygen demand (BOD$_5$), the chemical oxygen demand (COD), and the removal of total nitrogen (TN) and total phosphorus (TP) (Wakatsuki et al. 1993; Attanandana et al. 1997; Attanandana et al. 2000; Wakatsuki et al. 2000). Attanandana et al. (1997) found that an aeration rate of 24,000 liters/cubic meter/day over a 24-hour day once a month significantly increased the removal of total nitrogen and total phosphorus. It also increased the removal of BOD$_5$, a measure of the level of organic matter in water. The removal of BOD$_5$, total nitrogen and total phosphorus fell from 90.3, 90.8 and 90.1% to 48.2, 53.8 and 42.1%, respectively, after aeration.

However, too much aeration of the MSL system can inhibit nitrogen and phosphorus removal by slowing down the process of denitrification, and the translocation of ferric hydroxide from the soil mixture to zeolite inter-layers (Wakatsuki et al. 1993; Masunaga and Wakatsuki 1999). Therefore, aeration of the MSL system should take place at an appropriate rate and for an appropriate length of time.

Exactly what this rate should be is still being worked out. There are many factors to be considered, such as the quality of the wastewater to be treated, the temperature, indigenous microorganisms, and other conditions of the MSL system. Therefore, aeration of the MSL system should be adjusted according to local conditions. This study investigates the efficiency of MSL system in the temperate climate of Japan and the tropical climate of Thailand, respectively. The MSL systems described in this study had only the on/off regulation of aeration. It was therefore not possible to adjust the rate of aeration and see how this affected the efficiency of the MSL system.

THE MSL SYSTEM IN A TEMPERATE CLIMATE

The MSL system in Matsue city, Japan is contained inside a durable plastic tank measuring 1.75 x 2.5 x 1.2 m (Fig. 1). The soil mixture of the Matsue city MSL system consists of soil mixed with jute pellets, forest floor litter and small iron pellets (8 – 35 mm in diameter) at a ratio of 60:10:15:15 by weight, respectively.

Periodic aeration of the MSL system was investigated. The aeration period varied from 0 hours/day to 24 hours/day. Wastewater was sampled and analyzed before and after treatment.

THE MSL SYSTEM IN A TROPICAL CLIMATE

An MSL system was built at Kasetsart University in Thailand. It treated wastewater from the university cafeteria complex and associated toilets. The tank was made of concrete, and measured 100 x 200 x 150 cm (Fig. 3). The soil mixture consisted of clay soil (collected near the cafeteria), sawdust, and iron scraps in the ratio 75:10:15 (based on the dry weight). The soil mixture blocks alternated with layers of zeolite (Fig. 4).
Fig. 1. Structure of the MSL system, Japan

Fig. 2. Components of the MSL system, Japan
For aeration, a perforated aeration pipe 1.8 cm in diameter was installed in the middle of the system, so it would diffuse air uniformly throughout the tank when the aeration unit was switched on.

The wastewater from the cafeteria and toilets was initially pre-treated by being passed through a screen and five settlement tanks before being discharged into the MSL system. Loading rates ranged from 100 to 600 liters/square meter/day. The retention time of the wastewater in the MSL system ranged from five to 32 hours.

For the first few months, the MSL system was run without aeration. After that, changes in the pH of the MSL treated water were used to control the aeration of the MSL system. Aeration at a rate of 20,000 liters/cubic meter/day was applied to the MSL system when the pH rose to 7.0. This continued until the pH of the MSL treated water fell to 6.5, at which point aeration was stopped.
EFFICIENCY OF A MSL SYSTEM IN A TEMPERATE CLIMATE

Removal of organic matter

The MSL system was effective in removing BOD₅ in a temperate climate. At a period when the BOD₅ was at a low concentration (29-53 mg/liter), the efficiency of the MSL system in removing BOD₅ was 87-89%. Aeration made no difference to the efficiency of the system. If the wastewater contained a high level of BOD₅, removal efficiency was even higher, increasing to more than 94%.

Organic matter in the wastewater is an important carbon source for microorganisms. A high organic matter content or BOD₅ in wastewater significantly enhances microbial activity. This means that the microorganisms can more easily form a biofilm around soil and zeolite particles. This microbial biofilm assists the adsorption, and thus the decomposition, of organic matter in the wastewater.

Although aeration did not affect BOD₅, it had a marked impact on the removal of COD from the wastewater. The MSL system was much more efficient in reducing COD during periods of aeration. The COD removal increased from 59% during non-aeration to 82% during aeration. Since the COD represents slowly decomposing organic matter, intensive aeration is required to reduce the COD.

Nitrogen removal

The efficiency of the MSL system in removing nitrogen from wastewater is significantly affected by both aeration and temperature. The rate of removal was higher when there was no aeration of the system. Nitrogen removal depends basically on the intensity of nitrification and denitrification. When the MSL system was operated without aeration, the concentration of nitrate in the water after treatment was around 7.7 mg per liter. This was much lower than the nitrate concentration during the aeration period. During that time, the nitrate concentrated in the wastewater after treatment was 29.9 mg per liter.

The higher concentration of nitrate during the aeration period was because of the oxidation of NH₄⁺-N and inhibition of NO₃⁻N (nitrate) reduction. However, there was less total nitrogen removed during the non-aeration period (41.0%, compared to 46.8% during the aeration period).

The surface of the MSL system was covered in snow for several weeks over the winter. This tended to produce anaerobic conditions, which in turn enhanced denitrification, thus increasing the efficiency of the system in total nitrogen removal.

Phosphorus removal

Aeration of the MSL system is also a significant factor in improving the removal of phosphorus from wastewater. However in contrast to nitrogen removal, phosphorus removal was much faster during periods of aeration (around 89%, compared to around 56% during the non-aerated period). This indicates that aeration of the MSL system significantly enhances phosphorus removal. Low temperatures in winter did not affect the efficiency of the MSL system in removing phosphorus from wastewater.

EFFICIENCY OF A MSL SYSTEM IN A TROPICAL CLIMATE

Removal of organic matter

The efficiency of the MSL system in removing BOD₅ and COD from the combined toilet and cafeteria wastewater was dependent on the operational conditions of the MSL system and the quality of the wastewater.

Aeration was found to enhance the removal of BOD₅ and COD. This was particularly marked if the MSL system had been operating without aeration over a long period of time. In September, when the MSL system began operating without aeration, the efficiency of BOD₅ and COD removal was 84.1% and 90.0%, respectively. For the next two months, the MSL system operated continuously without aeration. Even after the aeration had stopped, the BOD₅ removal efficiency still increased because of the continuing effect of aeration. In contrast, the COD removal fell sharply. In October, BOD₅ removal reached its maximum value of 87.8%, whereas COD removal fell to 77.3%.

After this point, both BOD₅ and COD gradually fell to 75.2% and 64.5%, respectively.
During this period, there was no aeration. The slower rate in the absence of aeration was because the anaerobic conditions led to a reduction in the decomposition of organic matter in the wastewater.

When aeration began again in November, BOD and COD removal efficiency increased to 92.2% and 73.3%, respectively. The results indicate that aeration significantly enhances the activity of microorganisms which decompose the organic matter in the wastewater.

The rate of reduction in BOD had a more rapid response to aeration than COD removal, because BOD represents easily decomposed organic matter. In contrast, COD represents organic matter which is slower to decompose. This difference in response to aeration is important in managing the decomposition of BOD and COD through the control of aeration in the MSL system (Table 1).

**Nitrogen removal**

The efficiency of the MSL in removing total nitrogen depends on whether the conditions in the system are aerobic or anaerobic. Aeration enhances the efficiency of the MSL system in removing organic N by much as 100%. However, aeration of the MSL system at a rate of 4,000 liters/cubic meter/day for one week caused excessive nitrification, so that there was a high concentration of nitrate in the treated water.

When aeration was stopped for 1 – 2 weeks, the pH value of the MSL treated water increased to around 6.7. At the same time, the removal rate of total nitrogen increased.

**Phosphorus removal**

The MSL system was very effective in removing phosphorus, because of the capacity of the soil and iron pellets to adsorb and/or precipitate phosphate from the wastewater. Aeration enhanced phosphorus removal by forming ferric hydroxides, which strongly fixed phosphate from the wastewater. After aeration was stopped, anaerobic conditions developed in the MSL system. This enhanced the formation of ferrous ions, which are not effective in fixing phosphate (Masunaga and Wakatsuki 1999; Wakatsuki et al. 2000).

**CONCLUSION**

Aeration at an appropriate rate and for an optimum period of time significantly improves the capacity of the MSL system to reduce BOD, and COD, and remove nitrogen and phosphorus from the wastewater. Organic matter from the wastewater is first physically and chemically adsorbed at the surfaces of the soil blocks, and subsequently decomposed by microorganisms. Aeration is particularly important in a temperate climate. Intensive aeration is needed to increase the efficiency of the system during Japan’s cold winter.

Table 1. The effects of aeration on operation of the MSL system in a temperate climate (Japan) and a tropical climate (Thailand)

<table>
<thead>
<tr>
<th>Effect on operation of MSL system</th>
<th>Aeration</th>
<th>Non-aeration</th>
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<tbody>
<tr>
<td>Enhanced removal of organic matter.</td>
<td>Reduced efficiency in removing organic substances</td>
<td></td>
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<tr>
<td>(In both Thailand and Japan: enhanced removal of COD. In Thailand only: Enhanced removal of BOD)</td>
<td></td>
<td></td>
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<tr>
<td>Enhanced removal of total phosphorus by promoting formation of ferric hydroxides</td>
<td>Reduced efficiency in removing phosphorus</td>
<td></td>
</tr>
<tr>
<td>Enhanced nitrification</td>
<td>Enhanced denitrification</td>
<td></td>
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<tr>
<td>Higher nitrate content in treated wastewater</td>
<td>Lower nitrate content in treated wastewater</td>
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</table>
Although the effects of aeration are essentially the same in a warm climate (Thailand) and a temperate one (Japan), the high temperatures of Thailand’s tropical climate facilitate the faster decomposition of organic matter. Since BOD, represents the easily decomposed organic matter, aeration immediately increases the efficiency of the MSL system in removing BOD. The COD, however, contains organic matter which is slow to decompose. COD removal, therefore, needs more intensive aeration than BOD removal.

Nitrification and denitrification processes are the major mechanisms for nitrogen removal from wastewater in the MSL system. Hence, aeration is the most important factor. Changes in the pH of the MSL treated water is closely related to the processes of nitrification and denitrification, and subsequent nitrogen removal. The pH of the treated water from the MSL system should be kept at a level between 6.5 and 7.0 to maintain high efficiency.

Aeration at a rate of 20,000 liters per cubic meter per day, for three days, alternated with two months of non-aeration, was appropriate for the MSL system in Thailand. However, the rate and duration of aeration may need adjustment at other sites, depending on the quality of the wastewater and the components and structure of a given MSL system.

REFERENCES


DISCUSSION

In the discussion after the paper presentation, it was generally felt that the MSL system was an efficient way of removing both inorganic and organic pollutants from wastewater. One participant asked whether the components could be regenerated or recycled. Dr. Luanmanee explained that there is no need to replace the components, since the system can be used continuously for at least ten years. The system in Japan has been operating continuously for that period of time. Efficiency during the tenth year is as high as during the first year. Two tanks are needed for alternate use. If one tank clogs, the other tank is used for one or two months. During that time, the organic matter in the first tank will decompose.

Dr. Luanmanee was also asked whether the MSL system has been applied on a plant scale to treat wastewater. She explained that one unit can be used by 2-3 households.

Two important questions were the cost of treating the wastewater, and whether the unit emits an offensive smell. Dr. Luanmanee said that the cost is US$ 0.80 per cubic meter of treated water. The cost varies according to the components used, and can be reduced by substituting cheaper local materials. For example in Thailand, zeolite is expensive, and can be replaced by charcoal to reduce the cost. The system does not produce any unpleasant odor.