On-Site Treatment of Septic Tank Effluent by Using a Soil Adsorption System

Hui-Yu Hu[1]; Yi-Ling Cheng[2]; and Jen-Yang Lin[3]

Abstract: A septic tank and soil absorption system (SAS) is a simple means of treating domestic wastewater using the filtration, sedimentation, chemical absorption, and biological characteristics of soil. Data obtained from countries, such as the United States and Australia, where on-site wastewater treatment is common, suggests that SAS have become a main application for on-site treatment. In this research, the performance of SAS was investigated through an outdoor pilot study and two laboratory tank studies. The treatment capacity of the outdoor pilot plant was 1.5 m^3/day, and used alternating anaerobic and aerobic units. The objective of the pilot study was to verify the occurrence of nitrification and denitrification in the system. In the tank study, the first setup utilized capillary and siphonage mechanisms to change wastewater distribution within the filter bed. The effect of wastewater distribution on hydraulic loading, pollutant removal, and system reliability were then investigated. In the second setup, three different media (sand, gravel, and soil) were used to treat typical domestic wastewater to assess their removal of nitrogen and phosphorus-rich pollutants (including ammonia, nitrate, and TP). Last, three different hydraulic loadings were examined to investigate the maximum possible treatment loading. The pilot scale SAS experimental results show that through a batch system of anaerobic and aerobic units, the SAS was effective in removing nitrogen by nitrification and denitrification. In the pilot study, ammonia decreased by 76.0%, nitrate increased by 91.8%, and the sum of ammonia and nitrate decreased by 51.3%. Results from the water distribution test show that a minimum grain size of 2 mm should be used for the filter bed medium when capillary layers are used to distribute water. The hydraulic loading can be up to 50 L/m^2 day for a well-constructed capillary and siphonage trench. Results from the test with different filter media show that sand is the best of the three media tested in removing nitrogen and phosphorus. For typical nitrogen and phosphorus concentration of domestic wastewater, the influent concentration had little effect on the rate of reduction when sand and gravel were used. For hydraulic loading, under the maximum loading chosen in this experiment, ammonia nitrogen and phosphorus removal of greater than 90% still could be achieved for sand and soil. We therefore believe that hydraulic loading in SAS can be further increased to reduce the treatment site area.

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Introduction

To speed up sewage treatment in Taiwan, the Executive Yuan of Taiwan has included the construction of sanitary sewer systems as part of its "Challenge 2008—National Development Plan." The goal of the construction of sanitary sewer systems in this plan is to increase the wastewater treatment (including public sewerage and treatment facilities of buildings) from 17.8% in 2003 to 30.1% by 2007. As substantial funding and time need to be committed, the construction of sewer systems in urban areas and in environmentally sensitive areas has been given first priority, and the construction in rural areas has been incorporated into subsequent plans (CEPD 2003). It can hence be anticipated that domestic wastewater in the rural areas still cannot be satisfactorily treated in the immediate future.

Onsite wastewater treatment system (OWTS) is an alternative for treating wastewater in rural and unsewered areas in many countries. Septic tanks have been used in the United States to treat domestic wastewater since the late 1800s, and by the mid-1900s, septic tanks combined with subsurface gravel drains have become a main application of on-site wastewater treatment (USEPA 2002). According to the U.S. Census Bureau, approximately 25% of U.S. households in 2002 used OWTS for their domestic sewage: the most common type of which were septic tank and soil absorption systems (SAS). In addition to the United States, Australia also relies on OWTS as an alternative (O'Keefe 2001). Approximately 90% of the 250,000 unsewered properties in Queensland use SAS (Beal et al. 2004).

SAS work by directing wastewater into the soil through an underground diffuser; and as sewage flows through the soil pores, it becomes treated by means of filtration, sedimentation, chemical absorption, and biological reactions. From experiences, SAS combined with adequate pretreatment are able to treat domestic wastewater. The treatment process of SAS can be considered as a single-pass sand filter. In a sand filter, effluent is applied intermittently at the top of the sand bed and percolates slowly and evenly throughout the bed. The removal of effluent contaminants occurs

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mainly in the upper few centimeters of the bed where a biologically active layer is formed (Beal et al. 2005).

In contrast to other OWTS such as constructed wetlands and overland flow systems, treatment by SAS takes place underground, which protects humans and animals from physical exposure to wastewater and has no odor problem. A drawback of SAS is its higher complexity during construction; if careful considerations are not taken, contamination of groundwater is a possibility (USEPA 2002). Additionally, as the main structure is underground, it has little environmental or landscaping benefits. Further, if sufficient drainage or ventilation is not maintained, clog can occur as a result of soil particles bonding together and creating an anaerobic environment. Good ventilation at the filter bed is hence an important consideration for SAS (Beal et al. 2005).

The mechanisms governing purification and hydraulic performance of a SAS are complex and have been shown to be highly influenced by the biological zone (biomat) or clogging layer, which develops on the soil surface within the trench (Bouma 1975; Siegrist and Boyle 1987). The hydraulic conductivity of the biomat reduces over time with a concomitant increase in biomat resistance. With the increase in resistance, flow through the biomat is reduced to an extent that effluent can build up above the biomat while the underlying soil remains unsaturated (Kristiansen 1981). The unsaturated flow characteristics of the soil and the resistance properties of the biomat that govern the long-term flow rates though the biomat and subbiomat zone (Huntzinger and McCray 2003).

Biomat zone genesis and development is a dynamic process that can be influenced by physical, biological, and chemical processes. The dominance of any one process can be different to isolate as they often occur concurrently (Baveye et al. 1998). Biomat genesis is generally characterized by an initial physical clogging of the pores in the infiltrative surface of the native soil (Otis 1984; Siegrist et al. 1991). Anaerobic biological activity has commonly been identified as the main subsequent clogging process (Siegrist and Boyle 1987; Tyler and Converse 1994). Clogging usually occurs within the first few months of full operation of a SAS (Kristiansen 1981).

According to the U.S. *Onsite Wastewater Treatment Systems Manual*, 10–20% of SAS applications fail in the United States (USEPA 2002). The majority of the failures attributed to the SAS were not as effective in removing nitrogen substances (USEPA 1993), and the surcharging problem when the system hydraulic loading was exceeded (Brouwer et al. 1979; Geary 1994; Dawes and Goonetilleke 2001). From an overall viewpoint, biological denitrification is a two-step process that requires nitrification in an aerobic environment followed by denitrification in an anoxic environment. Nitrification is the sequential oxidation of ammonium–nitrogen to nitrite–nitrogen and then to nitrate–nitrogen. Biological denitrification reduces nitrate–nitrogen to nitrogen gas (Vesilind 2003). The redox status, soil microbial composition, and labile carbon source are the key factors that determine the degree of total nitrogen removal in a SAS (Wilhelm et al. 1994; EPRI 2000).

The biological process is the most important of SAS treatment mechanisms. The biomat formed between the filter bed and the on-site soil plays an important role in this regard, as biomat slows down the infiltration so that nutrient can be taken up by the microorganisms and plants. Solid pollutants can also be screened and intercepted by the biomat; however, this sometimes becomes a hydraulic issue as clog can occur and cause system failure (Beal et al. 2004, 2005). To reduce the clogging, one simple solution is to lower the system hydraulic loading. As recommended by the USEPA, a reasonably designed hydraulic loading for 150 mg/L BOD of wastewater should be between 9 and 36 L/m^2 day depending on soil type (USEPA 2002). A lower hydraulic loading, however, implies a larger land area requirement. For Taiwan, where available land area is scarce, this is not a workable solution. Hence, in this experiment, an attempt was made to increase hydraulic loading by changing the flow distribution within the filter bed.

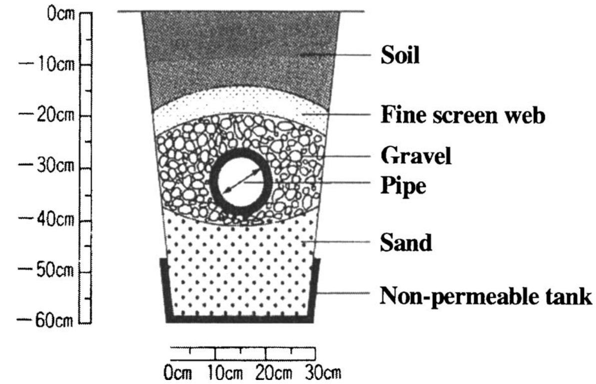

Fig. 1. Sectional view of water distribution by capillary action

In conventional SAS, wastewater passes through the gravel, the sand, and then the on-site soil. A method developed by a Japanese research institute (a schematic is shown in Fig. 1) suggested that wastewater could be passed through a gravel layer after flow distribution, and then into a 10–15 cm tall, nonpermeable tank filled with sand by infiltration. It was anticipated that as each batch flows into the nonpermeable tank, it would be drawn upward along the tank wall by capillary action. As water flows downward to the soil outside the tank, a siphon is formed and continues to draw water out of the tank. This method guides the wastewater batches by capillary and siphonage actions into the soil to be treated; hence, water will not pool up as a result of different infiltration speeds between two different media, which could cause growth of the biomat. Additionally, more suspended soils would be trapped inside the larger pores of the sand layer, reducing the possibility of blockage in the soil. Further, by running wastewater in batches, it was easier to maintain an aerobic condition for the sand layer inside the nonpermeable tank. Therefore, it is believed that this method increases system stability and reduces the probability of failure. According to the model developed by the Japanese Research Institute, a hydraulic loading as high as 67 L/m^2 day can be achieved using this method (Shimatani et al. 2003).

After reviewing SAS used in other countries, an underground pilot, as well as two experiment tanks inside a laboratory, was constructed in order to investigate the following:

1. By creating an anaerobic–aerobic–anaerobic environment in series, the system's treatment efficiency on nitrogen is investigated in order to develop a SAS that is capable of removing nitrogen effectively;
2. The influence of wastewater distribution within the filter bed on hydraulic loading, pollutant removal, and system reliability is investigated to determine the maximum system hydraulic loading and the least area required for a SAS; and
3. Different filter media were used to investigate their respective removal efficiency on nitrogen and phosphorus [including ammonia, nitrate, and total phosphorus (TP)], in order to determine the most effective medium.

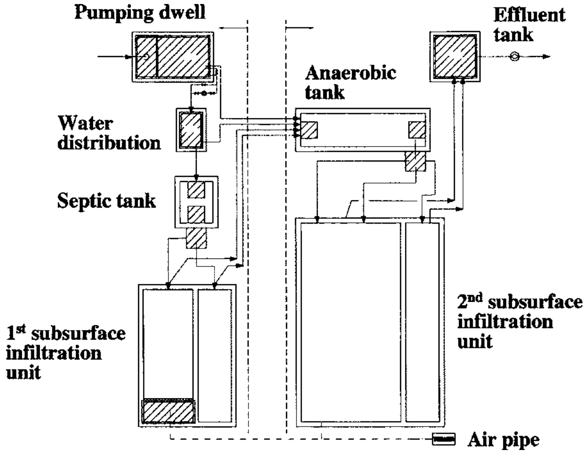

Fig. 2. Site plan of the pilot set up

Materials and Methods

Pilot-Scale SAS

In this study, the pilot plant was set up such that an anaerobic-aerobic–anaerobic environment is created in sequence. This was to facilitate the occurrence of nitrification and denitrification such that nitrogen would first be converted to nitrate, then to nitrogen gas, and finally released. The pilot plant was a 1.5 m^3/day SAS experimental facility that occupied 144 m^2 (12 m × 12 m) of land. The system included a wastewater diversion pipe, a pump, pretreatment, water distribution equipment, biological processing units, and a discharge pipe. The flowpath and site plan of the system is shown in Fig. 2. The component specifications of the pilot plant are shown in Table 1 (Shimatani et al. 2003).

The pilot plant was operated with the intermittent inflow and continuous outflow. Wastewater was fed into the pilot in 3 h batches. The pump will operate 5 min in every batch for pumping 187.5 L wastewater into the facility and flowed sequentially through the first septic tank, the first subsurface infiltration unit, the anaerobic unit, the second subsurface infiltration unit, and then discharged. The septic tank and the anaerobic unit are using the fixed-film process. To make sure the amount of carbon in the anaerobic unit was sufficient for denitrification, methanol, conventionally at a dosage of 3 mg/L per mg/L of nitrate–nitrogen, is used. Raw wastewater and primary effluent are unsuitable carbon sources because of their high ammonium and suspended solids concentrations, but these sources could be used if the resulting ammonium levels and shorter filter runs were acceptable (Vesilind 2003). In this study, 40% of raw wastewater was diverted to the anaerobic unit as a source of carbon provision. The second subsurface infiltration unit was set for treating the outflow from the anaerobic tank to make sure the concentrations of BOD (biochemical oxygen demand), ammonium, and suspended solids can meet the effluent standards. The efficiency of a treatment system can be evaluated in a number of ways, such as by the efficiency ratio, the summation of loads, the mean concentration, and the relative efficiency. OWTS, like BMP of nonpoint source pollution control, have different residence times. Hence, the effluent probability method (Strecker et al. 2002) and the box and whisker plot were used in this paper to evaluate system efficiency. These simple methods provided a clear measure of OWTS effectiveness and effluent water quality.

Table 1. Components Specification of the Pilot Plant

Components	Unit	Specification
1. Design flow	CMD	1.5
2. Pumping dwell	M	2.15×1.2×1.2 ($L\times W\times H$)
Pump	CMM×M×KW	0.10×3.0×0.15 ($L\times W\times H$)
3. Water distribution tank	M	1.0×0.6×0.6 ($L\times W\times H$)
4. Septic tank	M	1.25×1.2×1.85 ($L\times W\times H$)
HRT	h	48
5. First subsurface infiltration unit		
First trench	M	4.0×1.5×1.01 ($L\times W\times H$)
Second trench	M	4.0×1.0×1.01 ($L\times W\times H$)
Hydraulic loading of first trench	L/m^2 day	75
Hydraulic loading of second trench	L/m^2 day	110
6. Anaerobic tank	M	3.5×1.2×1.91 ($L\times W\times H$)
HRT	h	60
7. Second subsurface infiltration unit		
First trench	M	6.0×3.0×1.35 ($L\times W\times H$)
Second trench	M	6.0×1.0×1.35 ($L\times W\times H$)
Hydraulic loading of first trench	L/m^2 day	45
Hydraulic loading of second trench	L/m^2 day	60
8. Effluent tank	M	0.9×0.9×1.5 ($L\times W\times H$)

Water Distribution Test

To better understand the mechanism of water distribution, three tanks were constructed using acrylic polyethylene. The outer dimensions of the tanks were 0.8 m $L\times$0.5 m $W\times$0.5 m H, and the dimensions of the capillary distribution tanks on the inside were 0.28 m $L\times$0.5 m $W\times$0.1 m H. The dimensions and photo of the apparatus are shown in Fig. 3. The same soil mix as in the pilot plant was used to fill the tank except the capillary distribution tank, and the capillary distribution tank was filled with fine sand, quartz sand, and fine gravel, respectively. The main physical properties of the media and soil are shown in Table 2. The particle analysis of the media and soil is shown in Table 3. In the latter

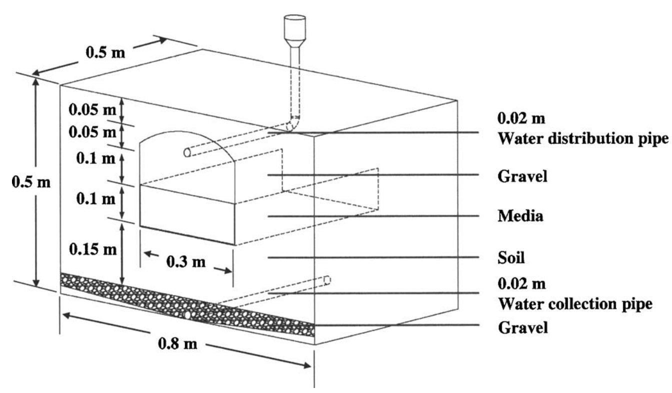

Fig. 3. Experiment of water distribution by capillary action

Table 2. Main Physical Properties of the Media and Soil

Sample	Bulk density (g/cm^3)	Porosity (%)	Water content (%)	Hydraulic conductivity (cm/s)
Fine gravel	2.00	29.6	0.03	0.07
Quartz sand	1.62	38.7	0.07	0.05
Fine sand	1.41	45.1	0.49	0.03
Soil	0.88	53.4	2.02	0.04

two tanks, a 1.4 mm thickness acrylic felt with 140 g/yd^2 was laid at the bottom of the distribution tanks to further enhance capillary action. Coarse gravel and a distribution pipe were placed on top of the distribution tank. Wastewater was fed into the pilot in 4-h batches. The pump will operate 6 minutes in every batch for pumping 7.2 L wastewater into the facility.

Test with Different Filter Media

Pollutant reduction efficiencies vary depending on the system filter bed medium used because of differences in medium properties (e.g., pore space and permeability). These differences affect not only the pollutant reduction efficiency but also the operating hydraulic loading limit. In this research, three different media were selected (soil, sand, and gravel) to treat domestic wastewater so that the efficiency on nitrogen and phosphorus removal could be evaluated. The tank used for the study was made of acrylic plastic and had dimensions of 0.5 m × 0.5 m × 1 m. The sewage distribution pipe was set up 0.1 m below the top of the tank and was made of PVC with a length of 0.4 m and a diameter of 1 cm. The pores on the diffuser were 10 cm apart, and each pore had a diameter of 0.5 cm. The diffuser was covered externally by a layer of gravel to ensure even distribution of sewage in the medium. The tank outlet (diameter 3 cm) was centered at the bottom so that the infiltration path of the sewage came close to 0.9 m before exiting the tank. A drawing of the apparatus is shown in Fig. 4. The experiment was operated in 3 h batches. The wastewater was operated with intermittent inflow and continuous outflow. Each time 374, 748, and 1,122 mL of sewage was added, depending on the hydraulic loading required. For each loading, the experiment continued for 20 days. Sewage was fed into the system using a pump running at 187 mL/min. The required loadings were obtained by running the pump for 2, 4, and 6 min, respectively.

Water Sampling and Analysis

For all of the three experiments, the wastewater was operated with an intermittent inflow and continuous outflow. The sampling frequency is twice a week for the pilot-scale SAS, and everyday for the test with different filter media. All of the water analysis in this study followed the code of National Institute of Environmental Analysis, Taiwan, which shown in Table 4.

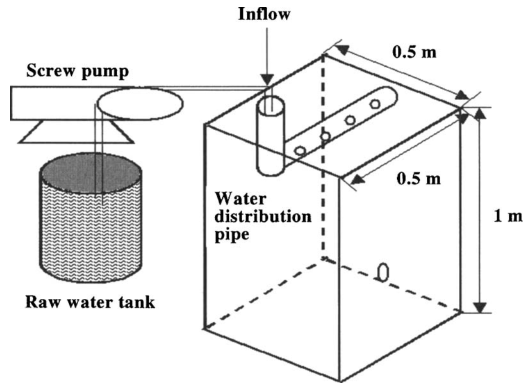

Fig. 4. Experiment setup to compare different filter bed media

Results and Discussions

Nitrogen Removal by Septic Tank and Soil Absorption in Series

Ammonia

Results from pilot operation revealed that the raw wastewater contained an ammonia level of 14.5–55.8 mg/L. The average concentration was 35.0 mg/L, and the median was 32.5 mg/L. This is slightly higher than typical domestic wastewater, because the samples originated from a recreational area without accommodation facilities. Hence, urine made up a high proportion of the total wastewater. The ammonia level after treatment by the septic tank was between 10.8 and 55.3 mg/L. On average, approximately 14.3% of the ammonia was removed by the septic tank. The ammonia level after the first subsurface infiltration unit was 9.0–39.0 mg/L, and the average removal was 35.3%. After passing through the anaerobic unit, the ammonia level decreased to 6.5–38.6 mg/L, and the average removal was 22.5%. After the second infiltration unit, only 1.5–35.8 mg/L of the ammonia remained, and the average removal was 57.7%. Overall, the system removed approximately 76.0% of the nitrogen.

To better understand water quality changes at each stage, probability and box and whisker charts were plotted (see Figs. 5 and 6). It can be seen that there is a 75% probability that the raw wastewater inflow would exceed an ammonia level of 25 mg/L, but after the first infiltration unit, there is a 55% probability that the level would be less than 15 mg/L. There is also a 75% probability that the final effluent would have an ammonia level of less

Table 3. Particle Analysis of the Media and Soil (%)

Sample	Clay <0.002 mm	Silt 0.002–0.05 mm	Sand 0.05–0.42 mm	Sand 0.42–0.84 mm	Sand 0.84–2 mm	Gravel 2–4 mm	Gravel >4 mm
Fine gravel	—	—	—	0.04	14.45	83.52	1.99
Quartz sand	—	—	0.73	72.94	26.33	—	—
Fine sand	—	—	36.1	45.61	14.00	4.29	—
Soil	5.00	5.00		90.00		—	—

Table 4. Water Analysis Methods

Items	Analysis method	Reference (American Public Health Association, American Water Works Association and Water Pollution Control Federation: Standard Methods for the Examination of Water and Wastewater)
BOD_5	NIEA W510.54B	20th Ed., Method 5210B, 5-3–5-6; APHA, Washington, D.C., 1998.
Suspend solid	NIEA W210.57A	20th Ed., Method 2540B and 2540D, 2-55–2-58; APHA, Washington, D.C., 1998.
Ammonia nitrogen	NIEA W446.52C	20th Ed., Method 4500-NH_3, 4-106–4-107; APHA, Washington, D.C., 1998.
Nitrate nitrogen	NIEA W417.51A	1. 14th Ed., 427–429; APHA, Washington, D.C., 1976. 2. *Methods for Chemical Analysis of Water and Wastes*, Method 352.1, EPA-600/4-79-020, Revised March 1983. 3. CNS 6232 K9050, National Standards of the Republic of China, 1980.
Total phosphorus	NIEA W427.52B	1. 20th Ed., Method 4500-P E, 4-146–4-147; APHA, Washington, D.C., 1998. 2. Environmental Monitoring and Support Laboratory. *Methods for Chemical Analysis of Water and Wastewater*, Method 365.2, 365.3; EPA, Cincinnati, 1983.

than 5 mg/L. This indicates a remarkable removal of ammonia by the system. The average effluent level was 8.4 mg/L ammonia, which satisfies the effluent standards of 10 mg/L.

Nitrate

The nitrate concentration of the raw wastewater was between 0.83 and 25.99 mg/L and had an average of 6.04 mg/L and a median of 4.06 mg/L. After septic tank treatment, this was reduced to 0.90–17.46 mg/L and indicated an average removal of −4.1%. After passing through the first infiltration unit, the nitrate concentration became 2.02–61.60 mg/L, and the average removal rate was −180%. After passing through the anaerobic unit, the nitrate level was between 1.09 and 22.68 mg/L, and the average removal was 44.4%. At the end of the system, the nitrate concentration was between 2.06 and 48.33 mg/L, and the average removal rate was −60.6%. Overall, the system removal rate of nitrate was −91.8%.

To better understand the effluent water quality at each stage, similar charts to Figs. 4 and 5 were plotted. These are shown in Figs. 7 and 8. It can be seen from the charts that except for between the first and second infiltration units, variations in nitrate concentration at different stages were not significant. This was attributed to the ammonia being nitrified to nitrate under an aerobic environment inside the filter bed. The average nitrate concentration of the final effluent was 11.58 mg/L, which met Taiwan EPA's effluent standards of 50 mg/L.

To understand the removal efficiency of SAS on other major domestic wastewater pollutants in addition to nitrogen, BOD, SS,

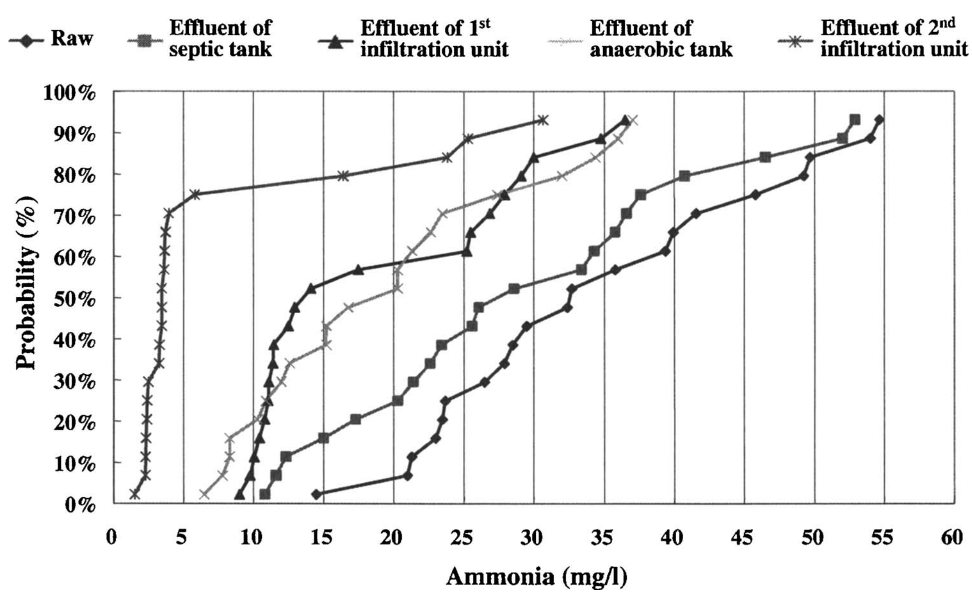

Fig. 5. Probability of ammonia concentration occurrence

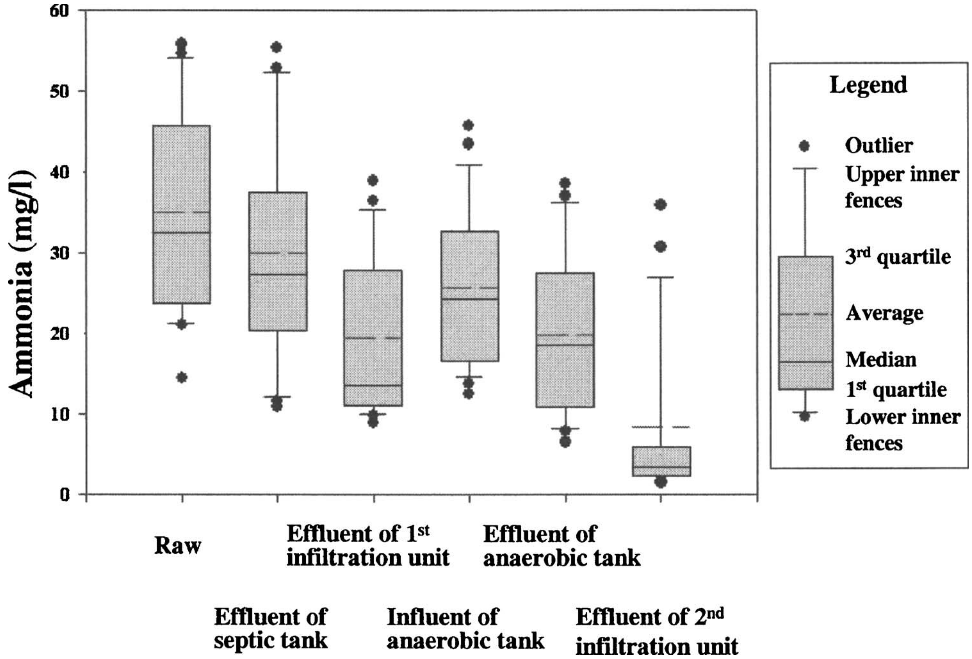

Fig. 6. Box and whisker chart for ammonia concentrations

and TP from the effluent were sampled at each stage for analysis and the results are summarized in Table 5. From the table, it can be seen that the final system effluent BOD level was 30.0 mg/L, which meets the effluent standards of 30 mg/L. The average SS concentration was 36.9 mg/L, which meets the effluent standards of 50 mg/L for buildings' discharge of 50–250 m^2/day. The average total phosphorus level was 1.62 mg/L and meets the effluent standards of 2.0 mg/L.

Increasing Hydraulic Loading by Changing Water Distribution

The primary objective of this method is to use the sand's larger pores to guide the wastewater into the nonpermeable tank, thereby reducing the possibility of water pooling up as a result of differences in infiltration speeds between media, which could cause growth of biomat. According to the experimental results obtained from this research, when sand was used inside the distribution tank, as wastewater seeped out of the gravel and onto the sand, it tended to form a pool on top of the sand due to the different permeability and then started to infiltrate the sand layer. However, after 30 days of operation, water tended to stay on top of the sand layer longer, and started to find its way to the outside of the distribution tank and overflowed into the soil layer. When this happened, the soil was eroded and channels were carved, hence when subsequent batches were fed, a large part of the feed

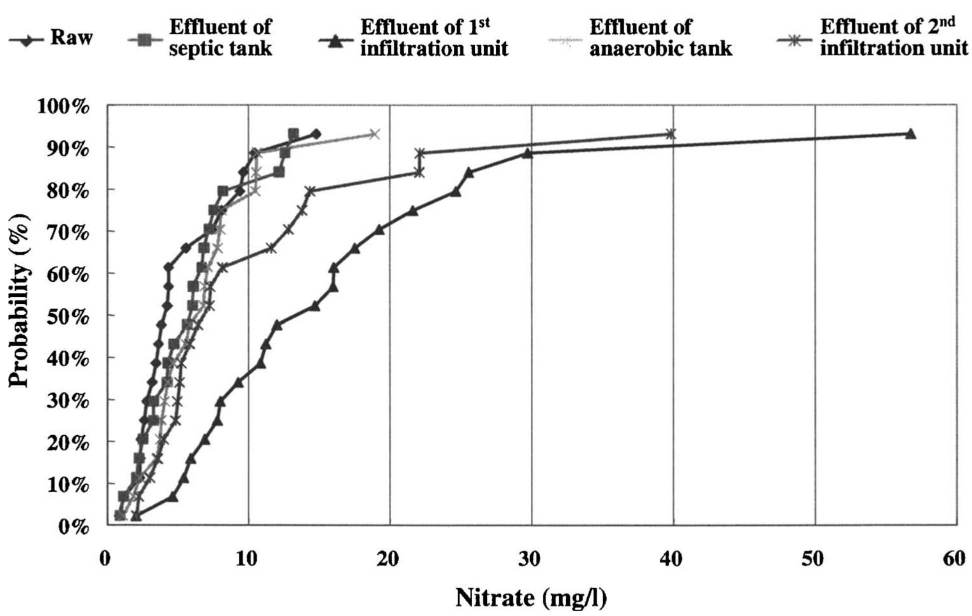

Fig. 7. Probability chart of nitrate concentrations

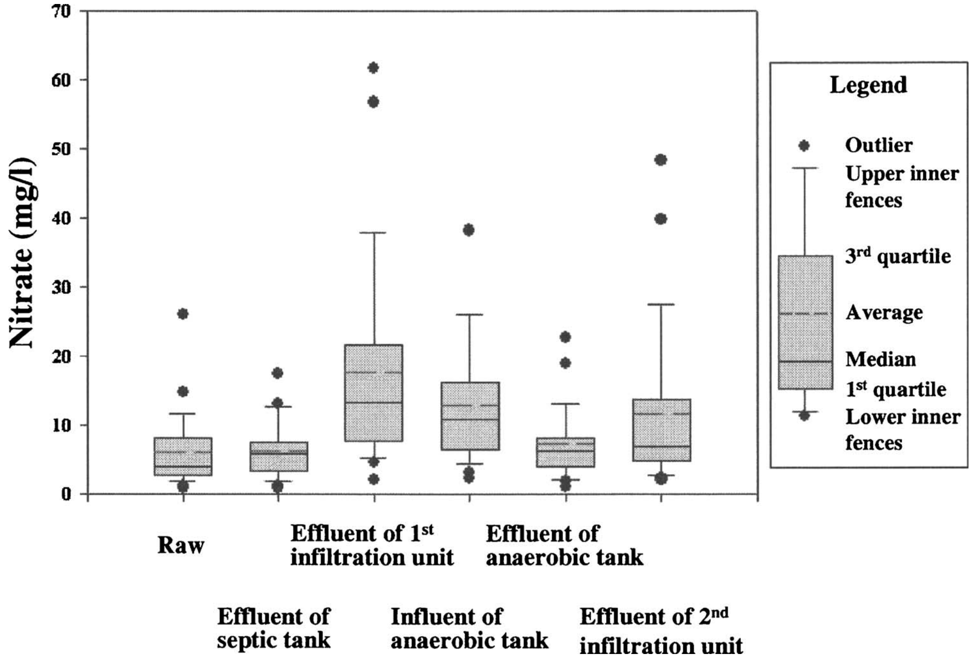

Fig. 8. Box and whisker chart of nitrate concentrations

always short-circuited its way to the soil layer. This eventually caused the system to lose its capillary and siphon mechanisms, and became a conventional SAS.

As for the other tanks, when fine gravel was used as the medium, the entire distribution tank could be filled up by a 1.2 L/min inflow in 6 min, and could be completely drained in 75–90 min. About 80% of the treated water could be drained from the soil infiltration tank in 180 min (see Fig. 9). When quartz sand was used, it only took 4.5 min to fill up the tank with the same inflow, but the water inside the distribution tank could not be completely drained until 300 min later. Only 56% of treated water could be drained from the soil infiltration tank in 240 min (see Fig. 10).

Based on the experimental results, if complete draining of the previous wastewater feed is necessary before the next batch can be fed, we recommend that the soil infiltration unit be designed with 2 mm minimum in grain size gravel (refer to Table 2, the particle analysis of the media) coupled with a permeable fabric that covers the bottom of the tank. For 3 h batches' operation, the hydraulic loading must not exceed 50 L/m^2 day for the treated water could be drained from the tank in 2 h. By using a hydraulic loading of 50 L/m^2 day, 20 m^2 in area would be required for each m^3/day of wastewater treated. If a two-stage system (in series) is desired for nitrogen removal, an additional 12 m^2 stage-1 soil infiltration unit (assuming 6:4 wastewater diversion was maintained) must be added. Together with the 3 m^2 occupied by the septic tank and anaerobic units, the entire system area would be approximately 40 m^2. If nitrogen removal is not required, the necessary land area could be reduced to 25 m^2.

Performance Evaluation between Different Media

Ammonia Removal

Among three different media (sand, gravel, and soil), sand was the best in removing ammonia (removal rate between 96 and 100%), followed by gravel (between 93 and 99%), and subsequently by soil (between 92 and 95%) (see Fig. 11). In terms of hydraulic loading, the removal rate by using sand and soil as media behaved normally under different hydraulic loading, but

Table 5. Average Concentration in Influent and Effluent and Removing Rate of Each Process

Average concentration and removing rate	BOD_5	SS	TP
Concentration in influent	106.8	81.6	6.5
Concentration in effluent of septic tank (mg/L) and the removing rate	87.7 17.9%	32.8 59.8%	5.8 10.7%
Concentration in effluent of first subsurface infiltration unit (mg/L) and the removing rate	42.6 51.4%	31.5 4.0%	2.9 50.2%
Concentration in influent of anaerobic tank (mg/L)	68.2	51.5	4.3
Concentration in effluent of anaerobic tank (mg/L) and the removing rate	49.5 27.5%	32.6 36.7%	3.1 28.8%
Concentration in effluent of second subsurface infiltration unit (mg/L) and the removing rate	30.0 39.4%	36.9 −13.1%	1.6 47.1%
Removing rate of the pilot plant	71.9%	54.8%	74.9%

Note: The anaerobic tank influent is composed of the effluent from the first subsurface infiltration unit and 40% raw wastewater.

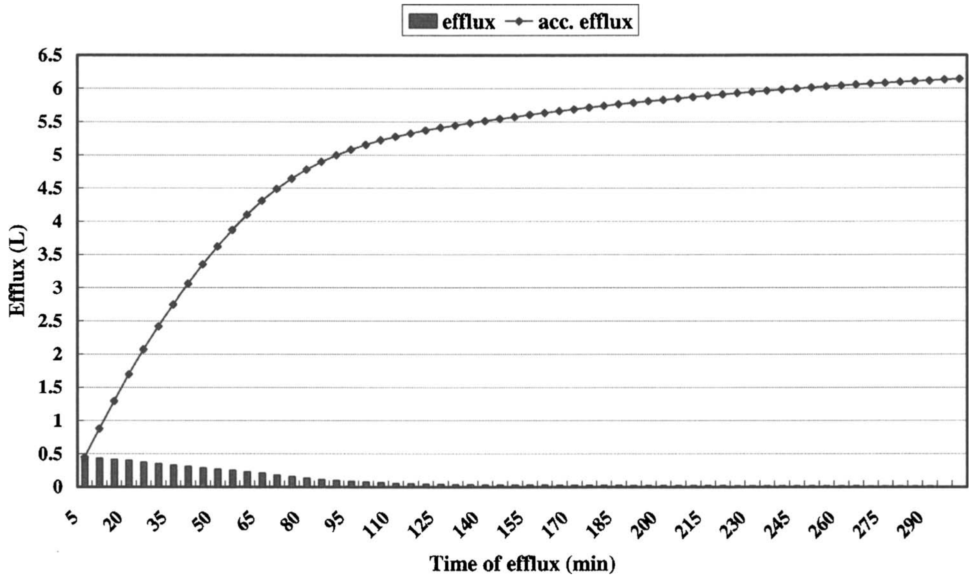

Fig. 9. Efflux from the water distribution tank that was filled with fine gravel

for gravel, as the hydraulic loading increased to 36 L/m^2 day, the removing rate of ammonia changed significantly.

Phosphorus Removal

Among three different media, the phosphorus removal rates of the sand and soil were similar with both in the range of 95%. This was due to the larger surface areas of the sand and soil particles, which resulted in higher phosphorus absorption. On the other hand, gravel has a larger particle size, and consequently, lower surface areas; hence, reducing its removal rate on phosphorus. However, if the hydraulic loading increased, the phosphorus may have re-released when use gravel as the treated media (see Fig. 12). If there were a high concentration of phosphorus (e.g., organophosphate) in the soil, the soil could have become less absorptive and hence a lower removal rate. There was no vegetation inside the experimental tank used in this research; hence, there was no plant uptake of phosphorus. As phosphorus is an essential nutrient for plants, plant uptake would have contributed to a higher removal rate of phosphorus.

Conclusions and Suggestions

1. A SAS that consists of two sets of alternating anaerobic and aerobic units is effective in nitrogen removal. From the pilot study, it was apparent that the anaerobic unit was the most effective in nitrate removal (44.4%) and ammonia removal (22.5%). The combined removal of ammonia and nitrate was approximately 29.8%. In the entire pilot system, 76% of ammonia (35.0–8.4 mg/L) was removed, and 91.8% of nitrate (from 6.0 to 11.6 mg/L) was accumulated. The combined re-

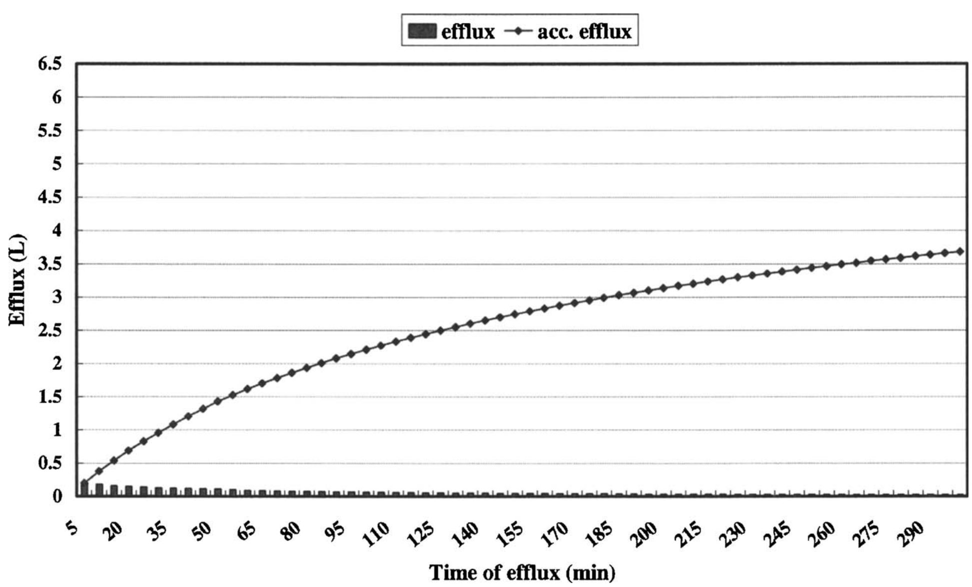

Fig. 10. Efflux from the water distribution tank that was filled with quartz sand

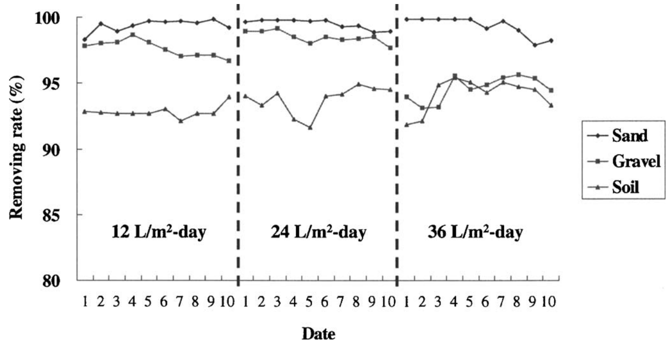

Fig. 11. Ammonia removing rate of different media in different hydraulic loading

duction of ammonia and nitrate was 51.3% (from 41.1 to 20.0 mg/L).

2. Compared to the USEPA recommended maximum hydraulic loading (33 L/m^2 day), the 67 L/m^2 day proposed by the Japanese Research Institute could more effectively reduce the land area requirement. However, this study found that when the filter bed operates under high hydraulic loading, its performance might be affected by the occurrence of short-circuiting. Blockage may also occur as a result of the growth of biomat.
3. When the soil pores filled up with water, the normal air exchange that takes place in the pores is inhibited. As a result, oxygen level could quickly drop to zero. However, when ventilation is maintained in the pores, diffusion of air could still take place from the atmosphere. Hence, to prevent clogging in the filter bed, inflow feed in batches and rotation of filter beds are necessary operational strategies.
4. The USEPA recommends a lower hydraulic loading but does not mention about rotational operations. Hence, if a system is designed with a conservative hydraulic loading (<33 L/m^2 day), maybe it does not need to be rested under normal operation. However, if a high hydraulic loading (≒50 L/m^2 day) is desired to reduce the treatment site, a break should be undertaken between operations for each unit. Based on this rotational requirement, it can be anticipated that schools and recreational areas would be the most suitable locations for installing SAS in Taiwan, as wastewater generation at these sites tends to follow an intermittent pattern. Schools and recreational areas are also typically more spacious and have needs for aboveground landscaping. Installing SAS not only achieves the purpose of wastewater treatment but also provides a natural landscape on top of the treatment facility.

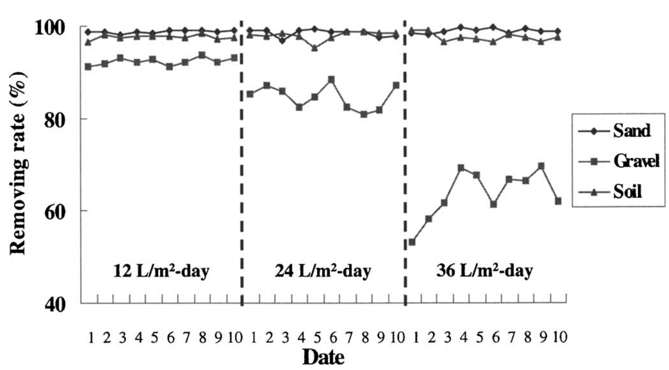

Fig. 12. Total phosphorus removing rate of different media in different hydraulic loading

5. The key factor to a stable SAS system is good air ventilation of the soil. Hence, when a soil filter bed is designed, sandy soil is preferred with a soil pore ratio of at least 50%, a conductivity of at least 10^{-2} cm/s. Since the system operates in batches, the distribution tank must be able to completely drain the previous batch before the next batch is allowed in; otherwise, water may pool up on top of the soil layer and cause clogs to form. Hence, in addition to filter medium selection, the draining speed and completeness of capillary action should also be considered. If necessary, fabrics that facilitate the speed of draining can be considered.
6. When sand and gravel are used as treatment media, inflow concentration does not appear to significantly affect removal rate of ammonia nitrogen and phosphorus.

The infiltration surface hydraulic loading rate (also called long-term acceptance rate) is a function of soil morphology, wastewater strength, and one of the SAS design parameters. It is used in the United States, Australia, and New Zealand to size the infiltration surface. According to the design criteria of these countries, the typical hydraulic loading rate of SAS is 5 to 33 L/m^2 day. To save space, we can use highly permeable soil to replace the onsite soil if low hydraulic loading is found suitable by an onsite soil percolation test. Using a capillary distribution trench may be an alternative for stable wastewater distribution in an SAS. In terms of future research, a greater understanding of the interactions between hydraulic and the media in the distribution tank is needed. Finding the better media for the capillary distribution tank, which can lead the flow path smoothly, will be a priority. Further work on the relation between the usage of the media and the hydraulic conductivity and the relation between the inflow rate and the biomat zone development are necessary.

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