Advanced Systems for Effective Use of Sewage Sludge Energy

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Project period: FY2000–2003

OBJECTIVES

Sewage sludge is the only energy resource derived from sewerage systems that can contribute to the energy and cost saving of the sewage works; therefore, the construction of a highly developed system utilizing such energy is needed. The aim of this study is to convert the current incineration process to a power generation process and reform the anaerobic digestion process into a power generating and heat recovering system based on effective use of methane gas.

METHODS AND RESULTS

We developed a new combustion system of dewatered sludge, composed of a 0.3-MPa pressured fluidized bed furnace, a ceramic filter and an air turbo-charger, which does not require external energy supply for combustion and can supply pressured air to the aeration tank of wastewater treatment. Figure 1 shows the flowchart of the developed combustion system. The pressured-adsorption gas storage tank was also developed for storing large amounts of digestion gas, with a capacity 20 times larger than the conventional atmospheric pressure storage tank of. The developed process and system are analyzed through case studies and the effects were evaluated.

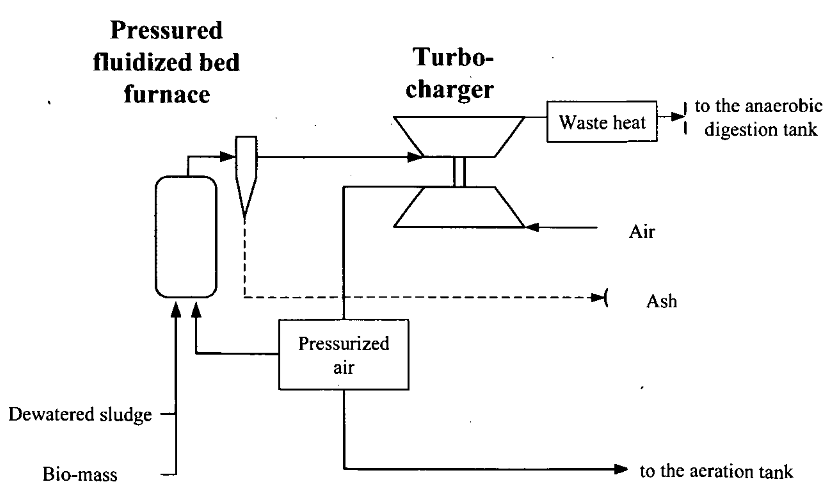

Figure 1 Flowchart of developed combustion system

Fate of Endocrine Disruptors in Sewage Sludge

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Project period: 2002–2005

OBJECTIVES

In recent years, numerous reports have been published on the environmental problems caused by endocrine disruptors (EDs) discharged as trace chemicals in many countries and regions. Among the manufactured chemicals necessary for daily life and activities, some of those that are used and discharged can disrupt the endocrine system of humans and wildlife. Detailed investigations on this problem have been conducted around the world. The Ministry of Construction carried out a national investigation on the pollution of river water and treated wastewater by EDs in FY1998; some trace chemicals suspected to be EDs were detected at almost all surveyed points. Research and investigation are needed to study countermeasures to deal with EDs in the sewerage system. This research aims to clarify the fate of EDs in the unit processes performed at sewage sludge treatment facilities and in soil that includes sewage sludge compost.

RESULTS

In FY2003, we carried out experiments to clarify the fate of nonylphenol (NP) and its related compounds such as nonylphenol polyethoxylates (NPnEOs) and nonylphenol polyethoxy carboxylic acids (NPnECs) in the anaerobic digestion process. NP is believed to be one of the EDs.

NP1EO, NP1EC, and NP2EC were spiked respectively to anaerobic digesters supplied with thickened sludge and the response was observed. NP1EO and NP1EC are considered as precursors of NP. NP2EC is considered as a precursor of NP1EC.

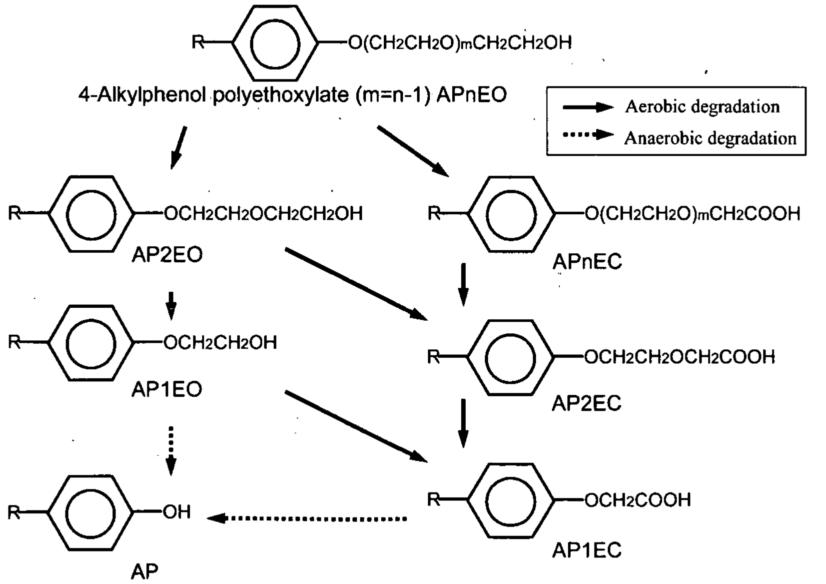

Figure 1 Decomposition of nonylphenol polyethoxylates (based on Ahel *et al.*)
AP: Nonylphenol, R: C9H19

Figure 2 shows the outline of a test apparatus. The volume of injected thickened sludge was 200 mL and the same volume of digested sludge was taken out, every day excluding holidays. The volume of digested sludge in each glass vessel was 4 L. Average retention time was approximately 28 days. The test was performed at a temperature of 35°C to simulate the mesophilic digestion.

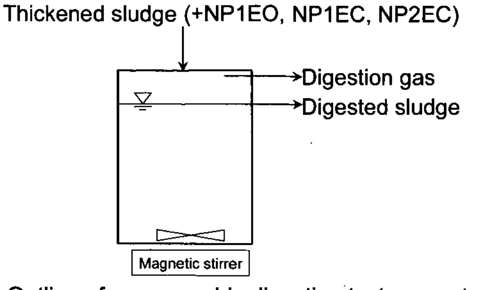

Figure 2 Outline of an anaerobic digestion test apparatus

Figure 3 shows the test results in which NP1EO was spiked. Approximately 40% of the spiked NP1EO was converted to NP.

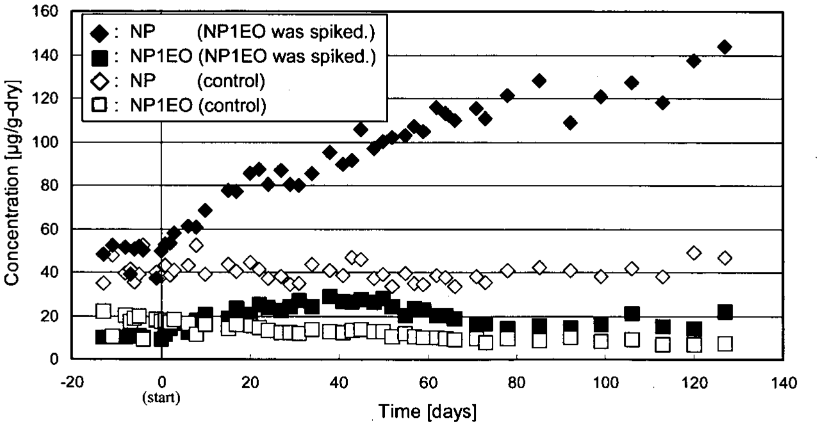

Figure 3 Decomposition of NP1EO and generation of NP in anaerobic digestion process

Almost all of the spiked NP1EC was converted to NP when injected to an anaerobic digestion testing apparatus with thickened sludge. When NP2EC was injected, conversion to NP did not occur until the 20th day.

In the coming years, it will be necessary to develop analysis techniques for the NPnECs in the sewage sludge sample to clarify the fate of NPs in more detail. It is also necessary to develop a technique for controlling NPs in the sewage sludge treatment process.

Reference

Ahel, M., Giger, W. and Koch, M. (1994). Behavior of alkylphenol polyethoxylate surfactants in the aquatic environment - I. Occurrence and transformation in sewage treatment. *Water Research*, **28**, 1131-1142.

Recycling of Organic Wastes by Utilizing Bio-Solids Treatment System

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Project period: FY2002–2005

OBJECTIVES

Large quantities of waste wood and grass are produced during civil engineering works and maintenance of green spaces such as road slopes, levees, airports and parks, and yet such wastes are scarcely used because of the lack of effective means. On the other hand, wastewater treatment plants consume large amounts of energy and organic substances; therefore, organic wastes have great potential as a substitute for such energy and organic substances. Moreover, bio-solids are a valuable microbiological resource containing many kinds of minerals and microorganisms.

This study aims at the development of a method for co-fermentation of organic wastes and bio-solids in the existing anaerobic digester of a wastewater treatment plant, to contribute to the recycling of organic wastes.

METHODS AND RESULTS

In FY2003, we carried out experiments in anaerobic digestion of a mixture of bio-solids and steam-exploded wood to determine the fluidity and dewaterbility of the digested slurry for the development of a co-fermentation process. We also carried out basic experiments in acid fermentation of waste wood using cellulose powder for the production of volatile fatty acids (VFA) that can be used as the electron donor in the denitrification process. It was clarified that the risk of increasing the load of digester mixer is low if the mixing ratio of steam-exploded wood to bio-solids is kept below 1, and that the water content of the dewatered slurry was lower than that of common digested bio-solids. The acid fermentation activity was high under the condition of pH ranging from 6.5 to 8, and the main product in such pH range was acetic acid, which reached the concentration of 10,000 mg/L (Figure 1).

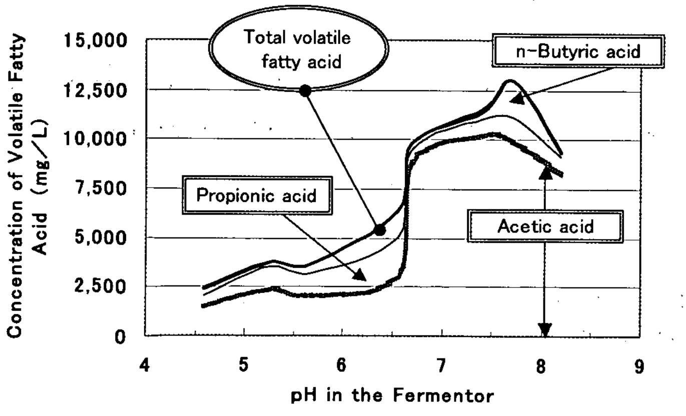

Figure 1 Relationship between pH in the fermentor and concentration of volatile fatty acid

Study on Risk Assessment for Reuse of Sewage Sludge

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Project period: 2001–2003

OBJECTIVES

It is necessary to promote the reuse of sewage sludge in order to establish a recycling-based society. At present, sewage sludge is recycled as construction material and fertilizer. In addition, ensuring sludge safety is important in order to promote its reuse.

The PRTR (Pollutant Release and Transfer Register) Law, which was enforced in 2001, stipulates that the sewerage manager must measure and report the behavior of heavy metal in the sewage treatment process. The goal of this study is to clarify the behavior of the heavy metal in the sewage treatment process and the elution amount of heavy metals from the sludge reuse products.

METHOD AND RESULT

Research results of FY2003 are as follows:

Elution amounts of heavy metals were examined using two elution test methods that differed mainly in the pH condition of the elution water. Elution characteristics differed among burnt construction materials, non-burnt construction materials and compost. From the elution results, health risks associated with heavy metal elution were calculated, revealing that almost all hazard ratios of reusing sludge for construction materials and compost were very low, but that those of As and Pb exceeded the value of 1 in sludge reused for fertilizer. Tables 1–3 show the results.

Further research is needed to clarify the fate of eluted heavy metals in the environment and the amount of human exposure to the heavy metals.

Table 1 Hazard ratio of burnt construction

Heavy metals	Burnt construction materials		
	max	min	average
B	1.7E-02	7.3E-04	7.6E-03
Mn	2.8E-01	2.1E-03	4.9E-02
Ni	6.6E-05	4.5E-06	3.0E-05
As	6.9E-02	1.1E-03	3.4E-02
Se	3.1E-02	5.0E-04	1.2E-02
Ag	1.5E-09	2.0E-10	3.9E-10
Cd	1.3E-02	2.0E-03	5.8E-03
Sn	8.0E-04	8.0E-04	8.0E-04
Sb	1.4E-02	3.3E-04	3.0E-03
Pb	5.2E-02	5.7E-04	6.8E-03

Table 2 Hazard ratio of non-burnt construction materials

Heavy metals	Non-burnt construction materials		
	max	min	average
B	1.2E-02	9.3E-04	4.7E-03
Mn	7.3E-03	4.2E-05	1.9E-03
Ni	1.2E-05	2.9E-06	6.3E-06
As	2.0E-01	1.0E-03	6.2E-02
Se	1.2E-03	5.0E-04	6.8E-04
Ag	2.0E-10	2.0E-10	2.0E-10
Cd	2.0E-03	2.0E-03	2.0E-03
Sn	1.8E-03	8.0E-04	1.1E-03
Sb	9.9E-04	3.3E-04	5.6E-04
Pb	3.8E-03	5.7E-04	1.4E-03

Table 3 Hazard ratio of compost

Heavy metals	Compost		
	max	min	average
B	3.0E-01	5.8E-02	1.5E-01
Mn	2.2E+00	5.4E-02	6.4E-01
Ni	2.9E-03	2.3E-04	1.3E-03
As	5.8E+00	6.0E-01	3.3E+00
Se	2.6E-01	1.4E-02	1.3E-01
Ag	1.2E-06	1.7E-08	4.6E-07
Cd	4.0E-01	2.5E-02	1.7E-01
Sn	1.9E+00	2.4E-02	4.0E-01
Sb	1.7E-01	3.3E-03	5.6E-02
Pb	5.5E+00	3.3E-02	1.1E+00

Study on Techniques for Identifying Pathogenic Microorganisms and Analyzing Their Behavior

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Project period: 1999–2005

OBJECTIVES

In order to prevent outbreaks of infection caused by pathogenic microorganisms contained in treated wastewater, reclaimed water and sludge, it is necessary to ensure that the treated materials are safe with respect to pathogenic microorganisms. The ultimate aim of this study is to adapt techniques of molecular biology (particularly the Polymerase Chain Reaction method) to pathogen detection methods due to the importance of developing a rapid and highly sensitive method for detecting trace levels of pathogenic microorganisms (such as viruses and protozoans) in natural water, treated wastewater and sludge. The study also aims to clarify the behavior of pathogenic microorganisms during the wastewater treatment process and in the environment.

The main areas of work performed during FY2003 are described below.

The study focused on the *Cryptosporidium* pathogen and virus. The method currently used to detect *Cryptosporidium* oocysts is microscopic observation of samples stained with fluorescent antibodies; however, this approach is unsuitable for wastewater samples, which have high levels of contaminants. We investigated a quick and simple quantitative detection technique based on the real-time PCR method.

RESULTS

In FY2003, we carried out experiments to evaluate the adaptability of the real-time PCR method to detecting *Cryptosporidium* oocysts, and it was found that the PCR method could be used as an alternative to the microscopic observation method.

For virus detection, concentration and elution methods were investigated and suitable methods for influent, effluent and tertiary effluent were proposed. Tables 1–2 show the results.

Table 1 Recovery ratio of phage by cellulose adsorbed and coagulation

	Treated eff		Advanced eff	
	Phage add	Phage non-add	Phage add	Phage non-add
Recovery ratio (%)	5.9	56	4.3	98

Table 2 Recovery ratio of phage by various collection methods

Collection method	Recovery ratio (%)		
	Influent	Treated eff	Advanced eff
Positively charged membrane	0.68	2.3	13
Negatively charged membrane	5.5	1.7	0.6
Ultracentrifugation	59	30	20
Polyethylene Glycol	58	36	38

Advanced removal of residual organic matter in secondary effluent for wastewater reuse

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Project period: FY2002–2005

OBJECTIVES

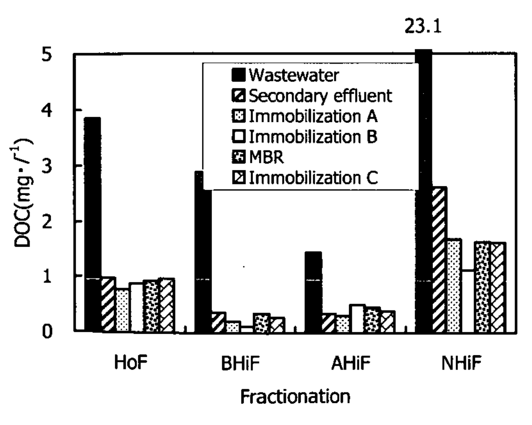
Treated wastewater is regarded as an alternative water resource in urban areas; however, residual organic matter may cause problems such as regrowth of microorganisms in distribution facilities and change of biota in water environments. This research aims at developing advanced removal methods of residual organic matter in an efficient and cost-effective way.

METHODS AND RESULTS

In FY2003, a binding immobilization process and a membrane bioreactor were applied to the advanced treatment of secondary effluent, and three kinds of fractionation methods using gel permeation chromatograph (GPC), ultrafiltration membrane and resins were employed for characterizing the organic matter in the influent and effluent samples.

The results of the research are as follows:

1) Microorganism regrowth potential evaluated as attached biomass was reduced to about half after the advanced treatment, which shows the effectiveness of the advanced treatment in controlling the regrowth potential.
2) Neutral hydrophilic fraction (NHF) was reduced by the advanced treatment (Figure 1), suggesting that NHF is related to the regrowth of microorganisms.



Here,

Immobilization A is treated secondary effluent.

Immobilization B is treated immobilization A effluent.

MBR is treated secondary effluent.

Immobilization C is treated MBR effluent.

Figure 1 Results of fractionation of dissolved organic carbon in wastewater, secondary effluent, immobilization effluent and membrane bioreactor effluent

HoF: Fraction of Hydrophobic Acid, BHiF: Fraction of Hydrophilic Base, AHiF: Fraction of Hydrophilic Acid and NHiF: Fraction of Hydrophilic Neutral Organics

Status of Pollution and Fate of Polycyclic Aromatic Hydrocarbons in Lake Sediment

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Project period: 2002–2005

OBJECTIVES

In recent years, environmental pollution caused by hazardous organic substances has become a severe problem. Organic compounds that are generated or used in the watershed are believed to concentrate in closed water bodies via rivers. In particular, several papers have reported on the pollution of bottom sediment of closed water bodies with polycyclic aromatic hydrocarbons (PAHs). Some PAHs such as benzo[*a*]pyrene are reported as probable human carcinogens. Therefore, it is necessary to clarify the status of pollution of sediment with PAHs and the fate of PAHs in lakes.

RESULTS

In FY2003, sampling of sediment from three lakes and analysis of PAHs in these samples were carried out.

Schematic diagrams of these lakes and sampling points are shown in Figures 1, 2, and 3. The surface and core sediment samples were collected from the bottom sediment of the lakes. Lake A, located in an urban area (Figure 1), was in a state of eutrophication. Lake B was located in a forest area (Figure 2), and there was no residence in the lake basin. These two lakes were selected to compare the effect of human activity on the occurrence of PAHs in the sediment. An artificial lagoon, C, was located in an agricultural area. Approximately 42% of the basin of the artificial lagoon was covered by agricultural area including a lotus field.
The amounts of PAHs were measured using GC/MS.

1. At the eutrophicated lake (Lake A), the contents of PAHs with more than four rings were high in the sediment. It was also revealed that the contents of PAHs in the sediment samples taken near the river mouth were high.

2. At the lake in the forest area (Lake B), the contents of PAHs with more than four rings were high in the sediment. The order of content of PAHs was almost equal to that in Lake A. It was also revealed that the PAHs load via atmosphere may have risen after the 1960s (Figure 4).

3. It was revealed that we could control the PAHs from the river using the artificial lagoon.

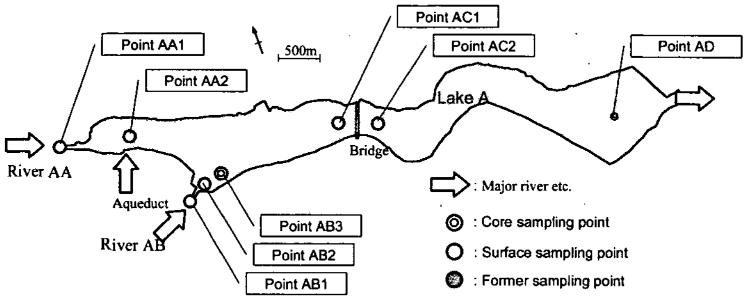

Figure 1 Sampling points in Lake A

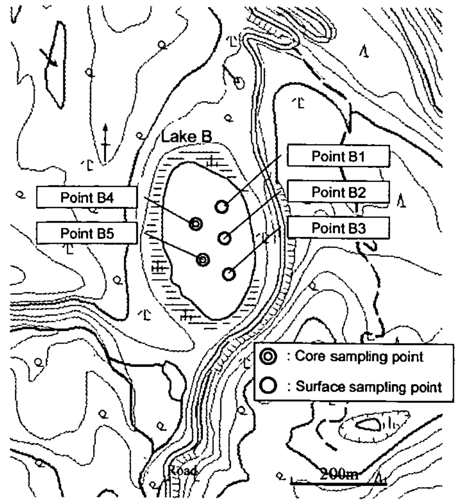

Figure 2 Sampling points in Lake B

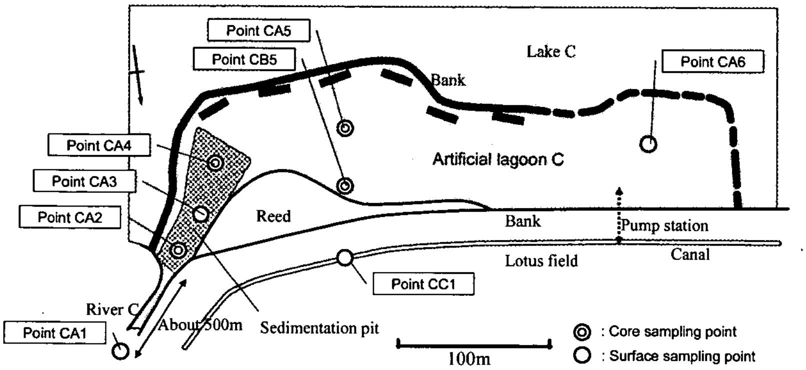

Figure 3 Sampling points in artificial lagoon C

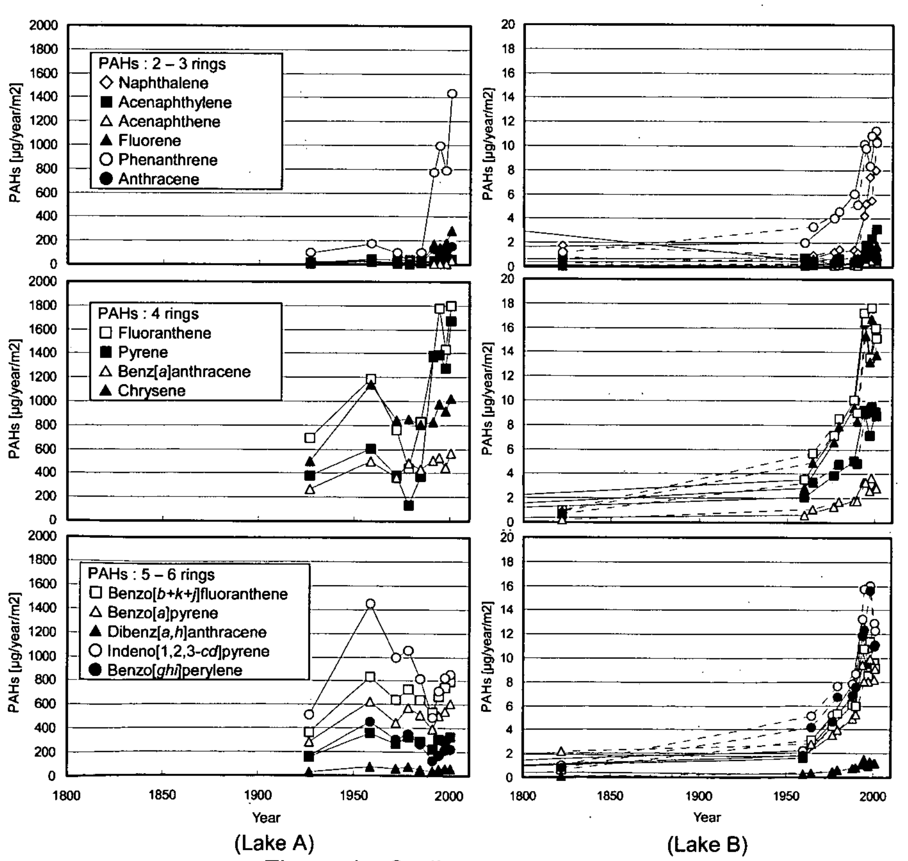

Figure 4 Sedimentation rate of PAHs

Study on technology utilizing waste wood and grass for revegetation

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Project period: FY2002–2005

OBJECTIVES

Large amounts of waste wood and grass are produced from public works. This study aims to develop technologies that effectively utilize such wastes to produce materials for planting at green spaces, and to propose a system of recycling such wastes in a closed area.

METHODS AND RESULTS

In FY2003, we carried out investigations to clarify the amount of waste wood and grass produced in specific areas. For example, the results of the investigation on generated driftwood is shown in Figure 1. Also, experiments were initiated to develop technologies utilizing waste wood as spraying materials for creating green spaces on slopes, and the results showed that the technologies using steam explosion for modification of wood structure reached a certain level for actual use.

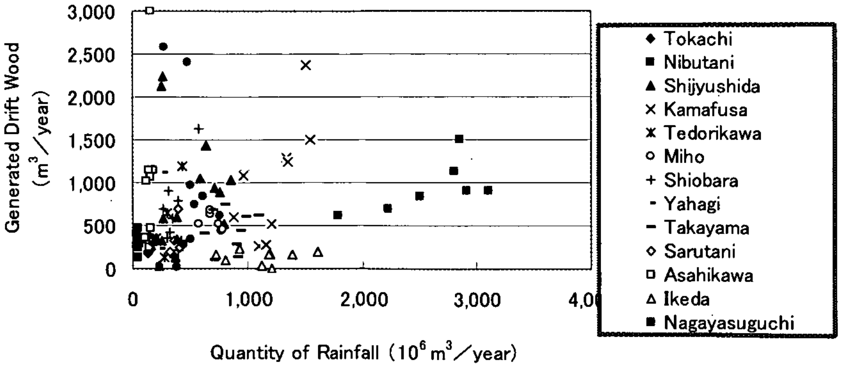

Figure 1 Relationship between the quantity of rainfall and generated drift wood in the 13 dam sites
(Here, the quantity of rainfall is calculated using the product of rainfall and drainage area.)

Fate of Pathogens in Sewage Treatment Plant in Monsoon Asia

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Recycling Research Team

Project period: 2003–2006

OBJECTIVES

Rapid population growth, urbanization, delayed sewerage system construction and intensive rainfall in Monsoon Asia have polluted urban water environments with pathogens originating from human feces. To evaluate the associated risks to people living in Monsoon Asia, the sources, routes and fate of pathogens in the water environment must be investigated. Most sewage treatment in Monsoon Asia is performed by lagoons, and the characteristics of the removal or inactivation of pathogens by these lagoons must be evaluated in terms of the effects of temperature, sunlight intensity and amount of rainfall. Lagoons are sometimes backed up by wetlands, and this supplemental process must also be performed efficiently.

This first aim of this research is to develop indicator microorganisms representative of the three pathogen groups: bacteria, protozoa and viruses. Then, these indicators will be applied to evaluate the effects of the type of lagoon, the wetland and the climate conditions on the fate of pathogens.

RESULTS

In the first year of the research, the following surveys were conducted using an experimental lagoon installed in a sewage treatment plant in Okinawa, Japan:

1) Effect of climate conditions and turbidity on the fate of pathogens in the lagoon.

2) Evaluation of the wetland to upgrade the efficiency of its pathogen removal following lagoon treatment.

Table 1 shows the results. The removal ratio was about 60 to 90% by the lagoon process; and about 10 to 20% improvement was obtained after wetland. As a result, total removal ratio was 70 to 99%.

Table 1 Concentration and removal ratio of pathogens

		Total coliform (cfu/mL)	Norovirus (copies/100ml)	Phage (Pfu/mL)	Giardia (cyst/L)	SS (mg/L)
Rainfall (removal %)	Influent	4.9E+5	1.8E+2	5.8E+3	1.0E+2	73
	Lagoon	1.0E+5 (79%)	1.9E+1 (90%)	1.9E+3 (68%)	2.0E+1 (80%)	67 (8%)
	Wetland	3.6E+4 (93%)	(−)	1.5E+3 (74%)	1.0E+0 (99%)	52 (29%)
Fine weather (removal %)	Influent	4.6E+5	5.7E+1	4.1E+3	5.6E+2	98
	Lagoon	1.1E+5 (77%)	2.2E+1 (61%)	1.2E+3 (71%)	2.4E+1 (96%)	108 (−)
	Wetland	2.1E+4 (95%)	(−)	1.0E+3 (76%)	1.5E+0 (98%)	63 (36%)