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Field survey of a sustainable sanitation system in a residential house

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Abstract: Sustainable sanitation is an approach for more ecological and sustainable water resources management. In this paper, we proposed one of the new integrated waste treatment systems: an "sustainable sanitation system" that includes separation of the black water from water system by a non-flushing toilet (bio-toilet), and a gray water treatment based on a biological and ecological concept. Sustainable sanitation system also converts the domestic waste to soil conditioners and fertilizers, for farmland use. As one of the case studies, Environmentally Symbiotic Housing in which people actually live using the bio-toilet for the black water treatment and the household wastewater treatment facility for the gray water was introduced. The availability of this system was investigated by analyzing the sawdust used in the bio-toilet and the quality of the effluent in the household wastewater treatment facility. As the result, the water content of the sawdust did not exceed 60% in any of the sampling points and the BOD and COD of the effluent of the household wastewater treatment facility were below 10 and 20 mg/L respectively, due to the low loading. Compared to the pollution load on the water environment created by the conventional system, it was found that the effluent of the house has a lower load than the tertiary treatment and the volume of the water consumption is 75% of the conventional system.

Keywords: bio-toilet; pollution load; sustainable sanitation system; water consumption

Introduction

In recent years, many symposia concerning sanitation have been held. The background to this research is an action plan adopted by the Johannesburg Earth Summit of 2002 which disclosed that "The proportion of persons who have no access to safe drinking water and the proportion of persons who have no basic sanitation facilities shall be halved by 2015." The percentages of such people are particularly high in developing countries, and the departure point for this research is the need for systems unlike conventional wastewater treatment systems, because installing the sewerage system all around the world is beyond the economic level of the world (Wildere, 2001). Naturally, excreta and garbage produced by households must be returned to the earth as nutrients.

The sustainable sanitation system is a new wastewater treatment system that incorporates a non-flushing toilet (bio-toilet) that converts excreta into a reusable resource (as fertilizer or humus for organic agriculture). This newly developed system includes the separation of black water from water system by a non-flushing toilet, composting feces, urine, and garbage waste and recycling nutrients, and a gray water treatment system based on a biological and an ecological concept. The objective is to protect human health and the environment while reducing the use of water and recycling nutrients.

This paper described the actual case of the coagent house installed a bio-toilet that does not use water, and hence minimizes the environmental load to the water environment. The results were obtained concerning the state of operation of the bio-toilet and the household wastewater treatment facility for the gray water.

1 Materials and methods

1.1 Location conditions and environmental measures at the house of research coagent

The house of research coagent is on a hillside that spreads in a conical shape around the Port of Nagasaki. Because the district is not fitted with a common sewer infrastructure, its residents generally either flush their toilets using a domestic wastewater treatment unit, or they install a vault and vacuum toilet which needs fecal waste collection routinely. Three people live in this house and they installed a bio-toilet in which excreta is decomposed into compost to treat the black water and the household wastewater treatment facility for the gray water.

1.2 Bio-toilet

The bio-toilet uses sawdust as an artificial soil matrix to decompose the excreta into compost, or even to form gas and humus. Inside the tank itself, a motor gently stirs sawdust; in the sawdust, the water content of the excreta evaporates as a result of the heat produced by heater and biological activity. After the organic material is composted, it is disposed of as waste material, along with the sawdust, for use as fertilizer. All that remains after this process are small amounts of phosphorus, minerals, salt, and humus

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(Nakagawa *et al.*, 2001).

Fig.1 shows the structure of the bio-toilet. The excreta placed in the sawdust in the tank is fermented and decomposed as it is agitated slowly by a screw-shaped rotating mechanism. The bio-toilet has a structure whereby sawdust is sent out, in small amounts, from the excreta inlet side to the removal opening side. A ventilation fan installed beside the bio-toilet keeps the interior of the house almost completely free of the smell of the excreta. The fermentation and decomposition reduce the volume of the excreta until it can finally be used as fertilizer in dry conditions. An appropriate condition is necessary to use bio-toilet hygienically safe (Nakagawa *et al.*, 2005).

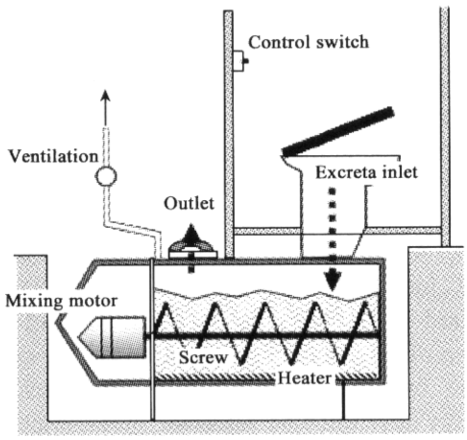

Fig.1 Bio-toilet structure

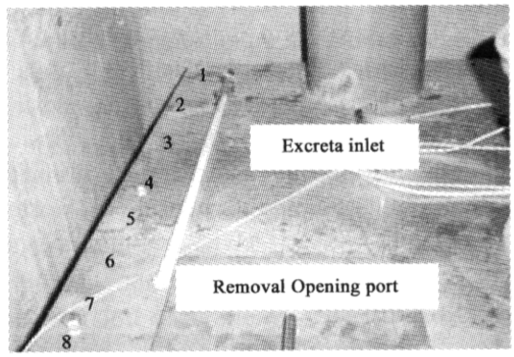

Fig.2 Treatment tank of the bio-toilet

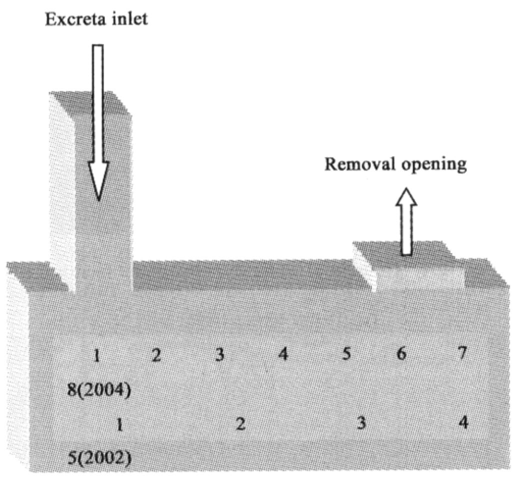

Fig.3 Locationof the sampling points
(2002): measured in 2002; (2004): measured in 2004

In order to clarify the degree of reduction of the excreta with sawdust inside the bio-toilet treatment, its water content, chloride ion concentration, and ash content were measured.

Fig.2 shows the bio-toilet treatment tank. The cover visible in the foreground is the compost removal opening, and the toilet is above the gray pipe, which can be seen in the back in Fig.2. This bio-toilet was installed in May, 2002. When 6 months passed, the sawdust was sampled from five locations, and each was analyzed. When 30 months had passed since its installation, the sawdust was sampled seven times (one time for day during one week) at each sampling point from eight locations as shown in Fig.3 and each was analyzed.

Water content is one indicator as to whether decomposition is proceeding well or not. The water content was measured by finding the weight (M) of the sawdust and the weight (M_d) after drying at a temperature of 105℃. The water content is defined by the following equation.

$$w(\%)=\frac{M-M_d}{M}\times 100 \qquad (1)$$

By measuring the chloride ion concentration, the weight loss of the sawdust inside the bio-toilet is estimated. Because the chloride ion is the excreta and urine origin, the amount does not change in the sawdust. 2 g sawdust was put into 200 ml of distilled water. After 10 min agitation, the voltage of the eluted solution was measured, and the calibration curve was made to indicate the relationship between chloride ion and voltage of solution. The chloride ion concentration was calculated using this calibration curve and the voltage results.

The ash content is another indicator of decomposition proceeding. Ash content was measured by finding the weight of the sawdust (M_b) then heating it in an electric furnace at a temperature of 600℃ for 3 h, and measuring the residue (M_a) to calculate the ash content (α). The ash content (α) is defined by the following equation.

$$\alpha(\%)=\frac{M_a}{M_b}\times 100 \qquad (2)$$

1.3 Household wastewater treatment facility (JOHKASOU)

A facility under the dotted line, as shown in Fig. 4, is the household wastewater treatment facility used for the gray water treatment. It is a facility to treat the wastewater with an aeration system and called JOHKASOU in Japan. Fig.5 shows the structure. The gray water settles into two settling tanks after separation and anaerobic decomposition, and it flows into an aeration tank. After aerobic decomposition in the aeration tank, the supernatant fluid is drained. The power consumption of the household wastewater treatment facility is 35 kWh per month and the treatment capacity is 1000 L/d.

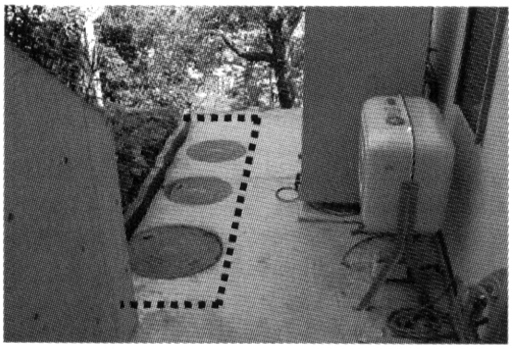

Fig.4 Household wastewater treatment facility

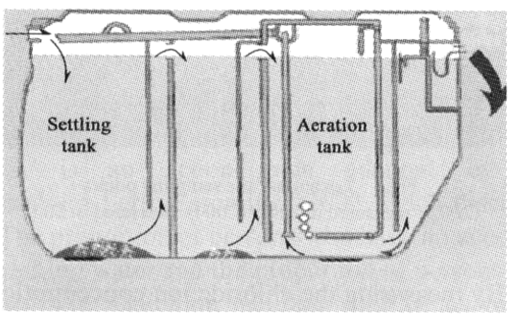

Fig.5 Structure of the household wastewater treatment facility

The BOD and COD of the influent and effluent of the household wastewater treatment facility were measured during one day in December, 2003, at 6 h intervals.

2 Results and discussion

2.1 Bio-toilet

Fig.6 shows the results of the water content testing at each of the sampling points. The sampling point numbers on the graph correspond to numbers indicated by 1 to 8 in Fig.3. The water content tended to decline over time, this is because the sampling points from the point closer to the removal opening were retained for longer time in the bio-toilet than others. Therefore, the rate of water content becomes lower as time passes. The water content did not exceed 60% in any of the sampling points. Generally, the water content criterion for appropriately performing composting is in a range from 40% to 60% (Morita *et al.*, 2002), so the results of this testing proved that the bio-toilet operates well. Compared with the results after six months of use, the rate of water absorption by the sawdust seems to be homogenized by agitation.

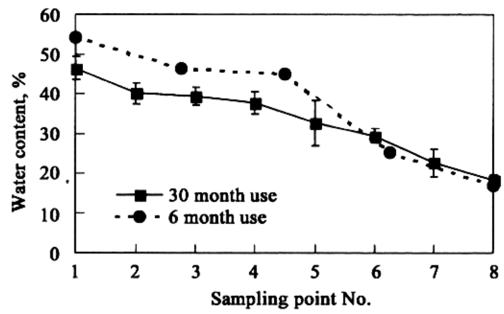

Fig.6 Water content in each sampling point

Fig.7 shows the chloride ion concentration results. Because the chloride ion content would be unchanged at sampling points 1 to 8, this change is generally considered to depend on the weight loss of the sawdust inside the bio-toilet. The difference of the value between sampling points No. 1 and No. 8 is assumed to indicate the efficiency of the decomposition. As the chloride ion concentration in the sawdust increases, the volume of the sawdust is considered to be decreasing. It can be said that the reduction of sawdust is not appeared clearly compared with the case after six months use. There is not significant difference between the measurements after six month use and thirty month use although the measurements after thirty month use are sure to increase more than measurement after six month use. One of the reasons is that 20 L of used sawdust was taken out as fertilizer, and new sawdust was put in instead during this two-year period.

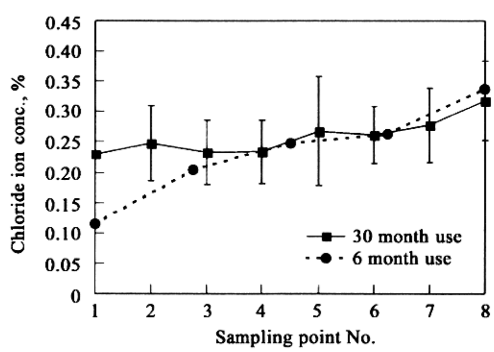

Fig.7 Chloride ion concentration in each sampling point

Fig.8 shows the changes of the ash content. The difference of the value between sampling point No. 1 and No. 8 is assumed to indicate the efficiency of the decomposition. It shows that, after six month use, the ash content increased significantly as decomposition advanced. Compared with the results of two years earlier, the ash content of sawdust (including excreta) seems not to have changed so much after 30 month

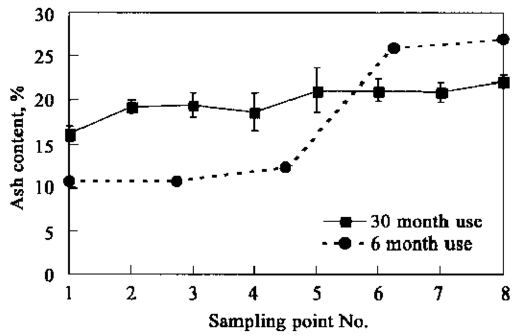

Fig.8 Measurement results of the ash content

use. One of the reasons for this is the deterioration of treatment efficiency.

Fig.9a shows the change of the relative weight of the sawdust (including excreta) to the chloride ion in the bio-toilet, as measured after six month use. This weight change of sawdust (including excreta) is calculated from the chloride ion concentration. Because the chloride ion is the excreta and urine origin, the amount of the chloride ion does not change in the sawdust (including excreta). Furthermore, the relative weight of the sawdust (including excreta) is divided into three ingredients: ash ingredient, water ingredient, and organic ingredient. The weight of the water ingredient was calculated by multiplying the weight of the sawdust per gram of chloride by the water content. Similarly, the weight of the ash ingredient was calculated by multiplying the ash content; it was assumed that the remainder is organic ingredient. While the evaporation of the water, emission of carbon dioxide gas during decomposition, and the emission of ammonia are assumed to reduce the weight of the sawdust, it is clear that water content has the greatest impact on overall weight reduction. Fig.9b shows the change of the relative weight of the sawdust to the chloride ion in the bio-toilet, as measured after 30 month use. It had been 2.5 years since the bio-toilet was installed in this house, and compared with results obtained two years earlier, the reduction of the quantity of the sawdust is not immediately apparent. One of the reasons is that 20 L of used sawdust was taken out as fertilizer, and new sawdust was put in instead during this two-year period; another reason is the assumed deterioration of the efficiency of the treatment method.

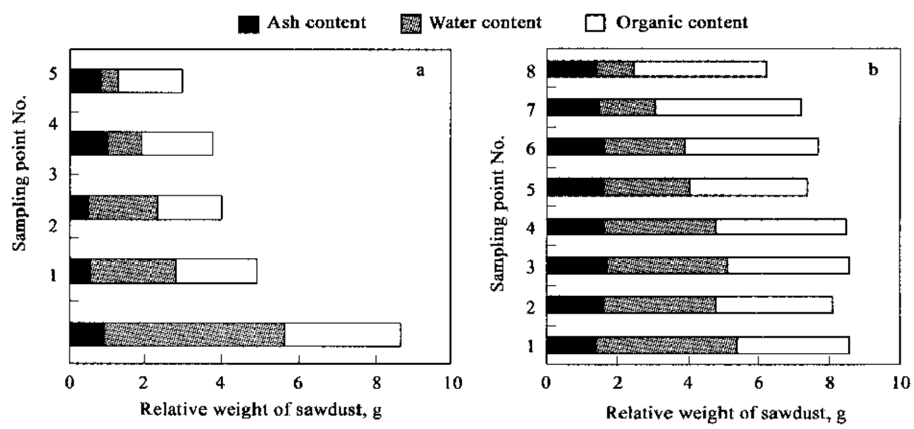

Fig.9 Change of the relative weight of the sawdust using 6 months(a) and 30 months(b)

The deterioration of the treatment efficiency happens as the porous of the sawdust is gradually clogged while using and the decomposition by the microorganism does not proceed. Therefore, changing the sawdust frequently or increasing the mixing rate to improve the aerobic condition is one of the solution to prevent the deterioration of the treatment efficiency.

2.2 Household wastewater treatment facility (JOHKASOU)

Fig.10 demonstrates the quality of the influent and the treated effluent, as sampled in December 2003. The influent and effluent of the household wastewater treatment facility were sampled and their quality was measured at 6 h intervals. The quality of the influent was a little low, with a BOD of 100 mg/L; there was a COD of approximately 40 to 50 mg/L, and it varied over time. However, no substantial fluctuations in the treated wastewater quality were seen. The BOD and its COD of the effluent were 10 and 20 mg/L respectively. The BOD and the COD of the supernatant were also measured after the water had been allowed to stand for a while. They were 5 mg/L or less. Given these results, it is assumed that the biological decomposition had proceeded well; however, there is a problem with the sedimentation separation process. This system was developed as the flush toilet wastewater treatment unit (It is called "gandoku-JOHKASOU" in Japan). Therefore it should be improved upon for the exclusive use of the gray water.

From the results of water quality testing, the environmental load this house discharged (concerning BOD, TN, and TP) was compared with that of the conventional system. The main methods of the

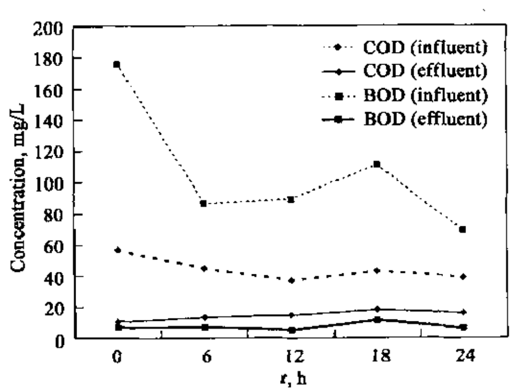

Fig.10 Quality of the effluent from the household wastewater treatment facility

conventional processing of the black water in Japan use a sewage treatment plant, the combine household wastewater treatment facility (It is called "gappei-shori JOHKASOU" in Japan), and tertiary treatment. The load on the water environment of the conventional system and this house (i.e., the newly-proposed sustainable sanitation system) were compared; BOD, TN, and TP in effluent were considered as indices of comparison. The results are shown in Fig.11.

Fig. 11a shows the environmental loads discharged per day per person in Japan; an average of BOD 40 g, TN 11 g, and TP 1 g (Ishizaki *et al.*, 2002). Figs. 11b and 11c refer to the system that processes

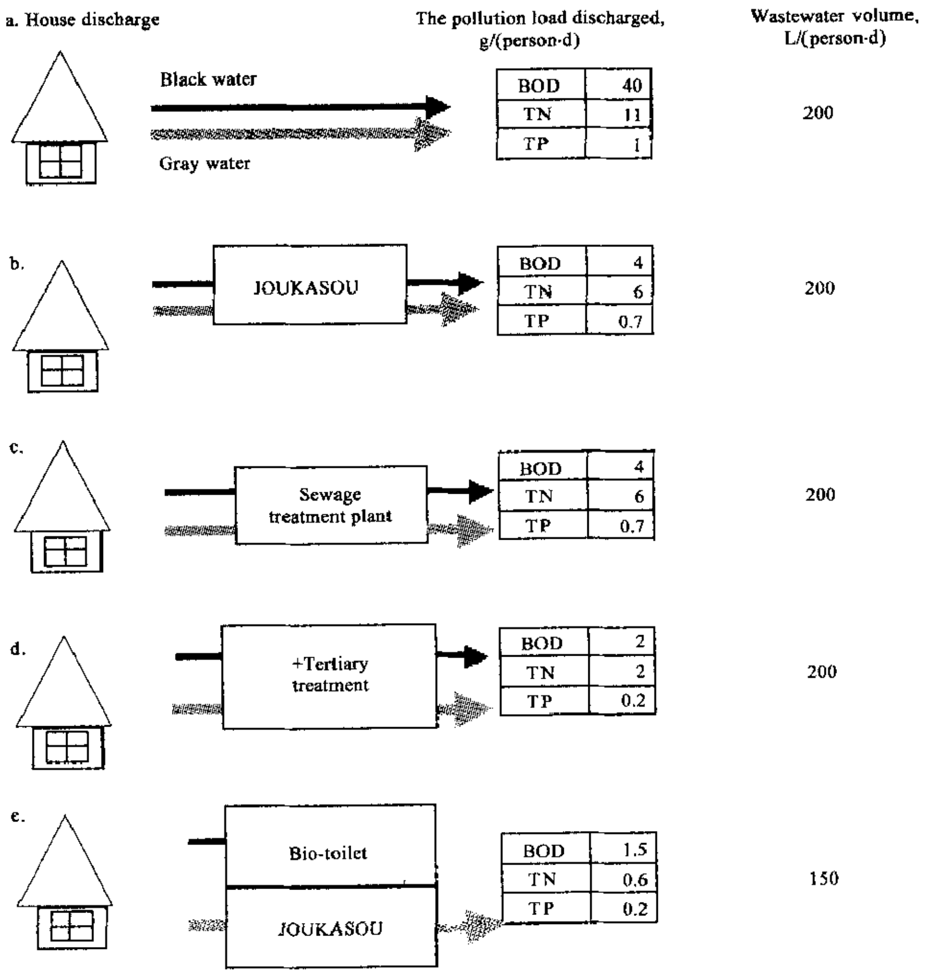

Fig.11 Comparison of the pollution load on the water environment

the black water and the gray water together, which is widely used in Japan. The water quality of effluent from a sewage treatment plant and the household wastewater treatment facility are assumed to be BOD 20 mg/L, TN 30 mg/L, and TP 3.5 mg/L (Ishizaki *et al.*, 2002). Fig. 11d refers to the case wherein the addition of the tertiary treatment in the sewage treatment plant is assumed; this system was introduced in about 13 plants in Japan. Tertiary treatment assumes that the water quality of the effluent is fulfilled (BOD 10 mg/L and TN 10 mg/L and TP 1 mg/L) using an anaerobic-aerobic treatment process and the physical chemistry phosphorus-removing method (Ishizaki *et al.*, 2002). In the cases of Figs.11a to 11d, the amount of water used per day, per person is assumed to be 200 L. Fig.11e refers to the case of this house, wherein the black water is not produced by the bio-toilet. Therefore, the load on water body from the bio-toilet is zero. The gray water in this house is treated by the household wastewater treatment facility, and the amount of the water used in this house is 150 L/(d·person); therefore, BOD, TN, and TP are 1.5 g, 0.6 g, and 0.2 g, respectively. This reveals that the effluent of this house (i.e., by way of the sustainable sanitation system) has a lower environmental load than the tertiary treatment system. Besides, bio-toilet does not use water at all, the volume of the supplied water and wastewater reduced to 75% of the case of Figs.11a to 11d. Indeed, by dividing and treating separately the black water and the gray water, the environmental load and the use of water can be reduced greatly.

3 Conclusions

In this research, a new wastewater treatment system called the sustainable sanitation system was introduced. As one of the actual case studies, Environmentally Symbiotic Housing incorporating a bio-toilet for the black water and the household wastewater treatment facility for the gray water was introduced. An analysis of the sawdust inside the bio-toilet treatment tank used in this house revealed that water content has the greatest impact on the weight reduction. As for the results measured after six months of use, the quantity of sawdust significantly decreased by the first stage. On the other hand, after 30 month use, the reduction of the quantity of the sawdust is not readily apparent. The results of measuring the water quality of the effluent in the household wastewater treatment facility revealed that its BOD and COD were 10 and 20 mg/L respectively. If sedimentation efficiency is improved, it is possible to drive these numbers to as low as 5 to 10 mg/L respectively. From the results of water quality testing, the environmental load this house discharged (concerning BOD, TN, and TP) was compared with that of the conventional system. Even when compared with the conventional system, it is revealed that the sustainable sanitation system can greatly reduce environmental load and the water consumption.

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