Activity to Reduce Sludge Generated from Septic Tanks to Zero Using Bacterial Method

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This paper describes an activity to reduce the sludge generated from septic tanks to zero. Several methods having the potential to reduce sludge emissions to zero were investigated, and a method using function-enhanced bacteria was judged to be the best from the viewpoint of cost-performance. This method was then tentatively applied to the septic tanks at Fujitsu's Nasu plant. In the trial, sludge emissions were reduced to zero at reasonable cost. Since the trial, the method has been regularly used in 15 plants in the Fujitsu Group, and about 1500 m^3 of sludge in total has been resolved by these bacteria. As a result, environmental burden has been greatly reduced, and the activity has contributed much to the achievement of zero emissions in the Group.

1. Introduction

In addition to business-originated waste such as disused chemicals, plastics, and paper, bio-originated waste such as the sludge generated from septic tanks is also imposing a great environmental burden. Based on this fact, it has been decided in Fujitsu that not only business-originated waste but also bio-originated waste will be the target wastes for zero emissions in the Fujitsu Environmental Program (Stage Ⅲ), which was started in 2001. In the program "zero emissions" is defined as zero disposal of waste outside of a company.

In 2000, about 2400 m^3 of the sludge generated from the Fujitsu Group was disposed of, but no effective measures for the sludge were taken. It was therefore necessary to tackle the issue in order to realize zero emissions.

However, at that time, practicable methods for reducing the sludge to zero were scarce, and it was a big task to find a promising method with good cost-performance that could be used to achieve zero sludge emissions.

This paper describes a bacterial method that we judged the most cost-effective method for achieving zero sludge emissions and describes how we demonstrated its practicability by applying it to plants in the Fujitsu Group.

The organization of this paper is as follows. Section 2 describes the reason why sludge must inevitably be discharged outside a septic tank. Section 3 compares various methods that can reduce excess sludge to zero, including a bacterial method that was judged to be the best from the viewpoint of cost-performance. Section 4 describes the first successful application of this method, which was in the septic tanks at Fujitsu's Nasu plant. Section 5 summarizes the results of applying this method and the tasks that remain for the future.

2. Why septic tanks generate excess sludge

2.1 Function of septic tanks

Figure 1 shows the schematic flow for treating organic drainage in a typical septic tank.

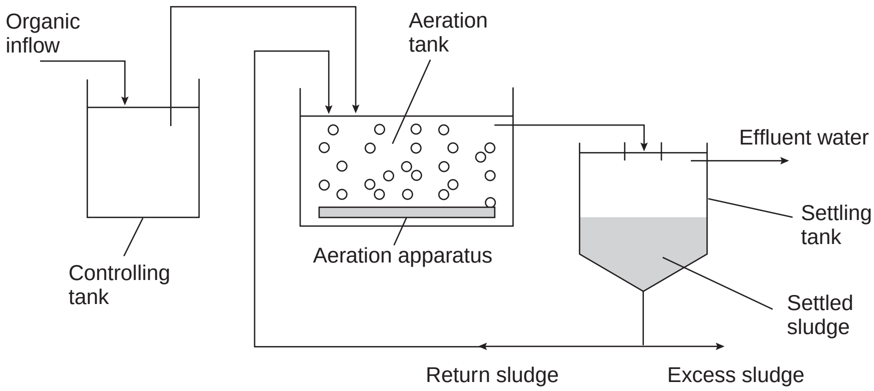

Figure 1
Flow for treating organic drainage in typical septic tank.

The flow is divided into the following stages.

1) The organic drainage flows to an aeration tank via a controlling tank, and fresh air is continuously supplied to the drainage in the aeration tank. Various kinds of aerobic bacteria living in the soil near the septic tank (hereafter, referred to as the native bacteria) populate the drainage and digest the organic matter by secreting enzymes. As the number of native bacteria increases, protozoa, which eat the bacteria, also increase in number. Therefore, a food chain is formed and a biological population living in structures called flocks grows in the aeration tank. **Figures 2** and **3** show a microscope image of a flock and the schematic structure of a flock, respectively. Suspended organic solids attach to the surface of a flock. The congregation of flocks is called the activated sludge, which, once formed, always exists in the aeration tank to a degree corresponding to the quantity of organic inflow.

2) The drainage containing the activated sludge successively flows to the settling tank after retention in the aeration tank for several to several tens of hours. After two to three hours in the settling tank, the activated sludge sinks to the lower part of the settling tank. This process increases the amount of

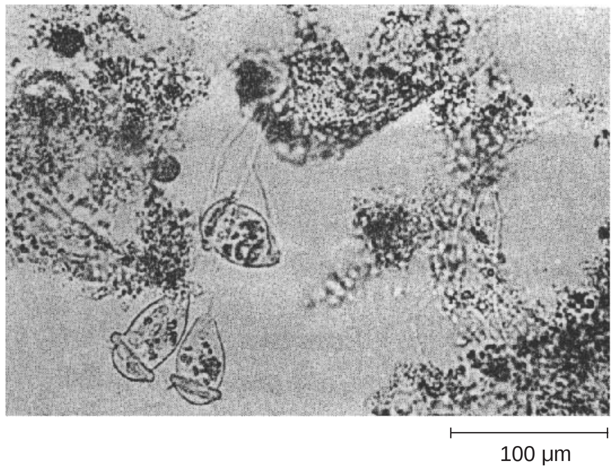

Figure 2
Microscope image of flocks in aeration tank.

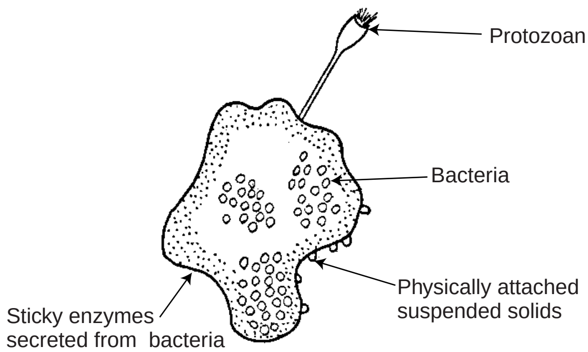

Figure 3
Structure of a flock.

settled sludge in the settling tank and leaves clear water at the upper part of the tank. The clear water is then discharged into a river.

3) Part of the newly settled sludge is returned to the aeration tank, and the remainder is discharged from the septic tank and disposed of.

In short, the three main operations are to purify organic drainage using native bacteria, which eat the organic matter in the drainage; discharge the purified water into a river; and dispose of the excess sludge.

2.2 Why excess sludge is generated

If the total amount of newly settled sludge is returned to the aeration tank, no excess sludge will be generated. This means that all of the native bacteria that are growing in the aeration tank will be used to digest the organic matter. However, if 100% of the newly settled sludge is returned to the aeration tank, the mass of activated sludge per unit volume of drainage, which is called the Mixed Liquor Suspended Solids (MLSS) value, will inevitably increase in the aeration tank for the reason described below.

Figure 4 shows the cell structure of a bacterium living in the activated sludge. The cell wall, the outermost part, includes a layer that has a firm structure, protects the cell from external mechanical forces, and prevents attacks from enemies. Inside the cell wall are the cell membrane and cytoplasm. If 100% of the newly settled sludge is returned to the aeration tank, there will be too many native bacteria for the amount of organic matter flowing through the tank, and some of the bacteria will die of starvation. Since the cell walls include the firm layers, which are hardly digested by the living native bacteria, the dead bacteria will accumulate in the aeration tank and cause an increase in the MLSS.

If this situation is allowed to continue, the following will happen. Firstly, the quantity of settled sludge in the settling tank will gradually increase until part of the sludge is carried over to the effluent, causing a deterioration in the purity of the treated water. Secondly, since the number of microbes in the aeration tank becomes excessive, oxygen destitution will occur in the tank and the organic matter will not be effectively digested. In order to avoid this problem, some of the settled sludge must be discharged outside the septic tank and the MLSS increase in the aeration tank must be suppressed. This is the reason why excess sludge in the tank must inevitably be discharged.

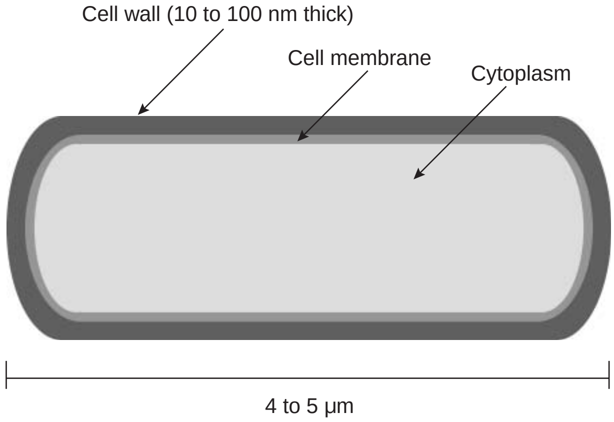

Figure 4
Cell structure of bacterium living in activated sludge.

3. Comparison of potential zero-sludge methods

To prevent the generation of excess sludge, the cell walls that are poorly resolved by the native bacteria must be changed into resoluble materials. We investigated and compared various methods that are considered to have such an ability (**Table 1**).

The first three methods in this table make use of the sludge treatment apparatus shown in **Figure 5**.

In the first method,[1),2)] ozone molecules generated in the apparatus destroy the cell walls by oxidizing them. This method has been shown to reduce the excess sludge to zero; however, the residual ozone causes both an increase in the Chemical Oxygen Demand (COD) and a deterio-

Table 1
Comparison of technologies for reducing excess sludge to zero.

Name of technology	Name of organization	Outline of technology	Evaluation
Ozone oxidation method	Kurita Water Industries Ltd.	Destroys the cell walls of the native bacteria using ozone oxidation and makes the sludge bio-resoluble.	Reduces excess sludge to zero, but the quality of treated water deteriorates. Apparatus is expensive.
Thermophilic bacteria method	Shinko Environmental Solution Ltd.	Makes cell walls of the native bacteria resoluble using themophilic bacteria.	Reduces excess sludge to zero, but some difficult-to-resolve substances are generated.
High-temperature and high-pressure water method	Ube Technical High School	Hydrolyzes the cell walls of the native bacteria using water in a sub-critical condition and changes them into bio-resoluble substances.	Reduces excess sludge to zero. Apparatus is expensive. Some technical problems remain in order to suppress an increase in operational cost.
Function-enhanced bacteria method	Daiwa Shoji Ltd.	Makes the cell walls of the native bacteria resoluble using certain kinds of bacteria that have an enhanced resolution function.	Reduces excess sludge to zero. No facility reconstruction is needed. Operational cost is reasonable.

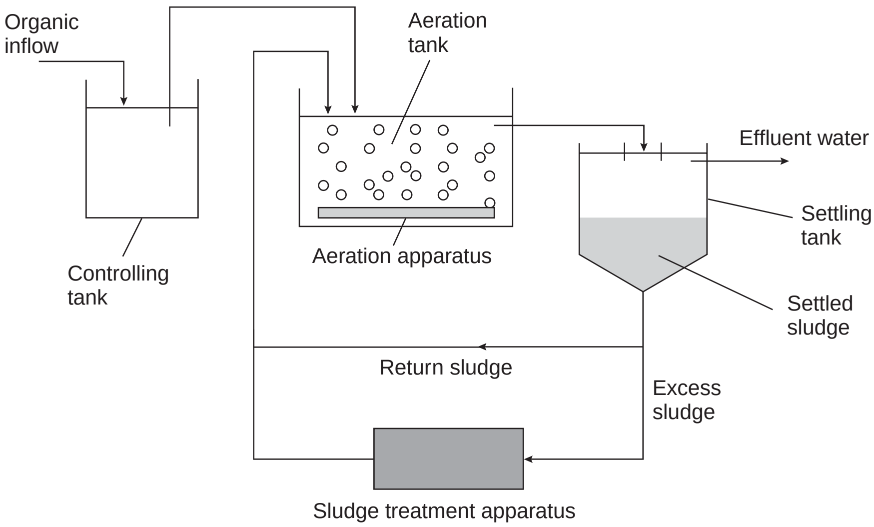

Figure 5
Flow used in first three methods listed in Table 1.

ration in the clarity of the treated water. Moreover, the ozone-generating apparatus is very expensive.

In the second method,[3] the temperature inside the apparatus is kept to about 65°C and the sludge is resolved by thermophilic bacteria having a high bio-resolution ability. However, it has turned out that an insoluble material created by this method deteriorates the purity of the treated water.

In the third method,[4] the apparatus is filled with water in the critical condition of 374°C and 22 MPa (165 000 mmHg), and this water hydrolyzes the sludge into bio-soluble materials. However, the apparatus is very expensive, and some technological problems remain to be solved in order to lower the operational cost.

In the forth method,[5] function-enhanced bacteria having a great ability to resolve the cell walls are periodically added to the aeration tank or the sludge storage tank of an existing septic tank. It has been demonstrated that under optimal conditions, this method can reduce the amount of excess sludge to zero. Furthermore, there is no need to reconstruct an existing facility, and the operational cost is lower than that of the other methods because no electricity, thermal energy, or chemicals are required.

After comparing these methods, the fourth method was found to be the best from the viewpoint of cost-performance. Here, a description of these function-enhanced bacteria is added. These bacteria have been developed by the following procedure. Various bacteria living in nature were cultivated in the sludge, and after a series of cell divisions, specific bacteria that acquired a great ability to resolve cell walls were extracted. The cultivated bacteria are apt to be easily defeated by native bacteria in the life struggle. Therefore, in order to fully exhibit their ability, they must be added periodically (more than once a month) to maintain their dominance over the native bacteria. Since they will rapidly die outside of the sludge, there is no danger of them polluting the environment.

4. Application of function-enhanced bacteria method to septic tanks at Nasu plant

Since this method has been judged the most promising for realizing zero sludge emissions, it was tentatively applied to the septic tanks at the Nasu plant for about half a year as a first example of application. The sludge emitted from this plant was not recycled but was disposed of at a municipal facility.

1) Outline of septic tank systems at the Nasu plant

There are two kinds of tank systems, System 1 and System 2 (**Table 2**). System 1 has one aeration-settling tank series, and System 2 has three, one of which, so far, has not been used.

2) Reduction of excess sludge generated from System 1 to zero

Figure 6 shows the treatment flow. The bacteria were added in the aeration tank once a month, and we attempted to reduce the excess sludge to zero.

The quantity of bacteria that was added was determined as follows. The quantity of incoming organic matter, A, was determined by multiplying the Biochemical Oxygen Demand (BOD) of the organic inflow by the quantity of inflow. The quantity of bacteria required for a unit mass of organic matter, B, was deduced from a preliminary experiment, and the quantity of added bacteria was calculated as A/B. However, this value is applicable only to a steady state. Therefore, for the first three months, the quantity was set 40% above this value to make the bacteria the dominant species in the aeration tank as early as possible.

The effect of the bacteria can be ascertained by investigating the change in MLSS in the aeration tank, which is shown in **Figure 7**. No

Table 2
Outline of septic tanks in Nasu plant.

Item	System 1	System 2
Number of persons	450	1500
Equipment capacity	60 m^3/day	200 m^3/day
Average inflow of drainage	50 m^3/day	100 m^3/day
Discharged amount of excess sludge	70 m^3/year	140 m^3/year
Type of treatment	Long retention-time aeration type	
Number of aeration-settling tank series	1	3 One series is disused.

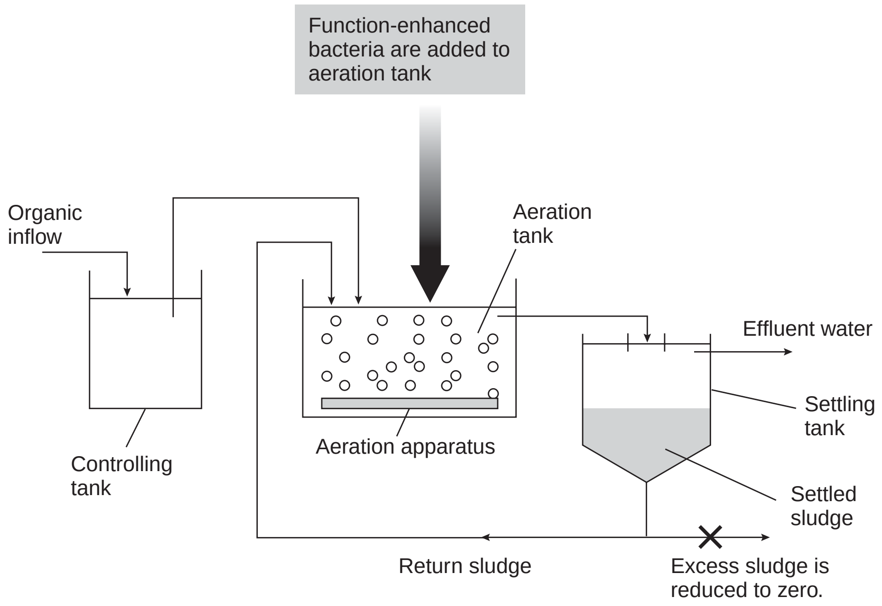

Figure 6
Treatment flow in System 1 septic tank of Nasu plant for function-enhanced bacteria method.

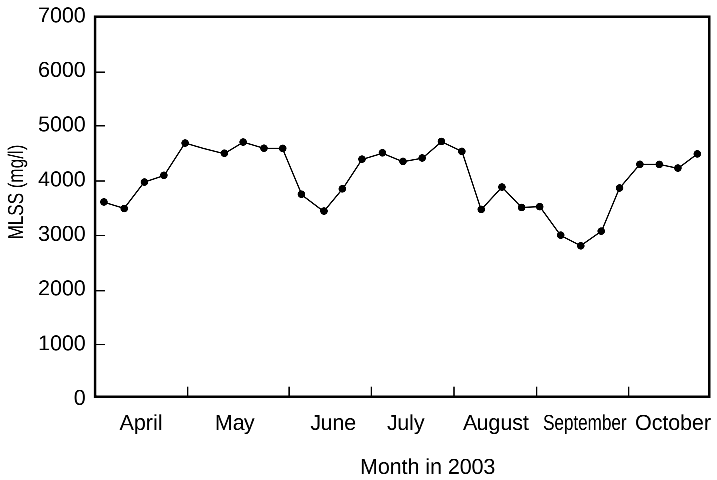

Figure 7
Change of MLSS in aeration tank of System 1 septic tank of Nasu plant.

increase in MLSS means that the bacteria have totally resolved the sludge. The MLSS even decreased between August and September. This decrease means that the resolution ability was excessively strong compared to the amount of sludge, because, in this period, the quantity of organic inflow was less than anticipated. In such a case, the size of the flocks forming the activated sludge often becomes minute and the settled sludge expands. **Figure 8** shows the change in the depth of the sludge interface, which is the interface between the clear water and the settled sludge, in the settling tank of System 1. From Figures 7 and 8, it can be seen that the decrease in MLSS and the expansion of the settled sludge happened in nearly the same period. In order to weaken the resolution ability of the bacteria, the quantity of added bacteria was decreased to half

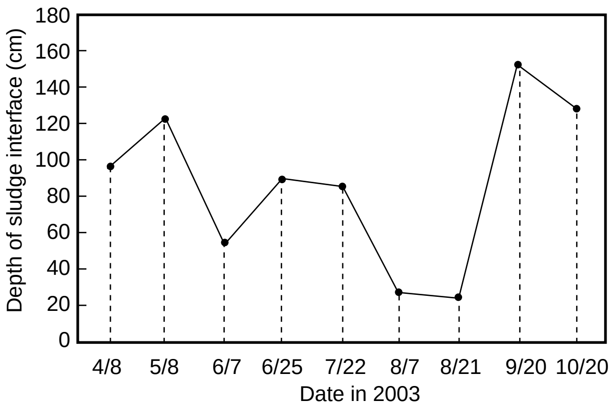

Figure 8
Change in depth of sludge interface in System 1 settling tank of Nasu plant.

of A/B from August to October. These figures show that the MLSS and depth of the sludge interface improved in October.

3) Reduction of excess sludge generated from System 2 to zero

Figure 9 shows the treatment flow in System 2. As shown in Table 2, System 2 has one aeration-septic tank series that, so far, has not been used. Therefore, the disused series was used to resolve the excess sludge.

The following sequence was adopted for System 2.

- The excess sludge stored in the sludge storage tank was transferred to the disused aeration tank at the rate of 10 to 20 m^3 per month, except for the first month, in which 59 m^3 of the sludge was transferred.
- Then, the bacteria were added to the disused aeration tank and aeration was started.
- Aeration was continued for about 25 days, during which time the sludge was resolved by the bacteria.
- Aeration was stopped, and the sludge was kept still for several days.
- About 10 to 20 m^3 of clear water formed in the upper part of the tank and was transferred to the controlling tank. The empty space in this tank was used to contain the sludge to be transferred.

As shown in Table 2, the amount of excess sludge that was discharged was 140 m^3/year or about 11.7 m^3/month. On the other hand, the quantity of transferred sludge was 127 m^3 in half a year or about 21 m^3/month. The difference between these two monthly figures means there was no discharge of excess sludge outside the tank.

The quantity of bacteria that was added was determined in the same manner as for System 1.

Using the disused series to resolve the sludge has an advantage over the method adopted in System 1 in that the series being used can be controlled independently of the operations for reducing the sludge to zero.

Figure 10 shows the change in MLSS in the disused aeration tank. The sharp increases in MLSS correspond to the points where the excess sludge was transferred. The gradual decreases in MLSS result from resolution of the sludge by the bacteria. The fact that MLSS goes down every time to about 6000 mg/l means that the increased amount of sludge due to the transfer was totally resolved.

Figure 11 shows the change in the depth of the sludge interface in the settling tank being used. The stable transition in the depth means that the method did not deteriorate the coagulation quality of the activated sludge.

4) Influence of the method on the quality of treated water

The quality of the treated water was monitored at the outlet of the tanks by measuring its pH; transparency; COD; BOD; number of coli phages; and concentration of n-hexane, nitrogen, and phosphoric acid before and after the method was applied. No distinguished changes in these quantities were observed. From this result, the quality of the treated water is considered to be uninfluenced by this application.

5) Comparison of the cost of treating excess sludge before and after the method was applied

We compared the unit costs of treating 1 m^3 of sludge before and after the method was applied.

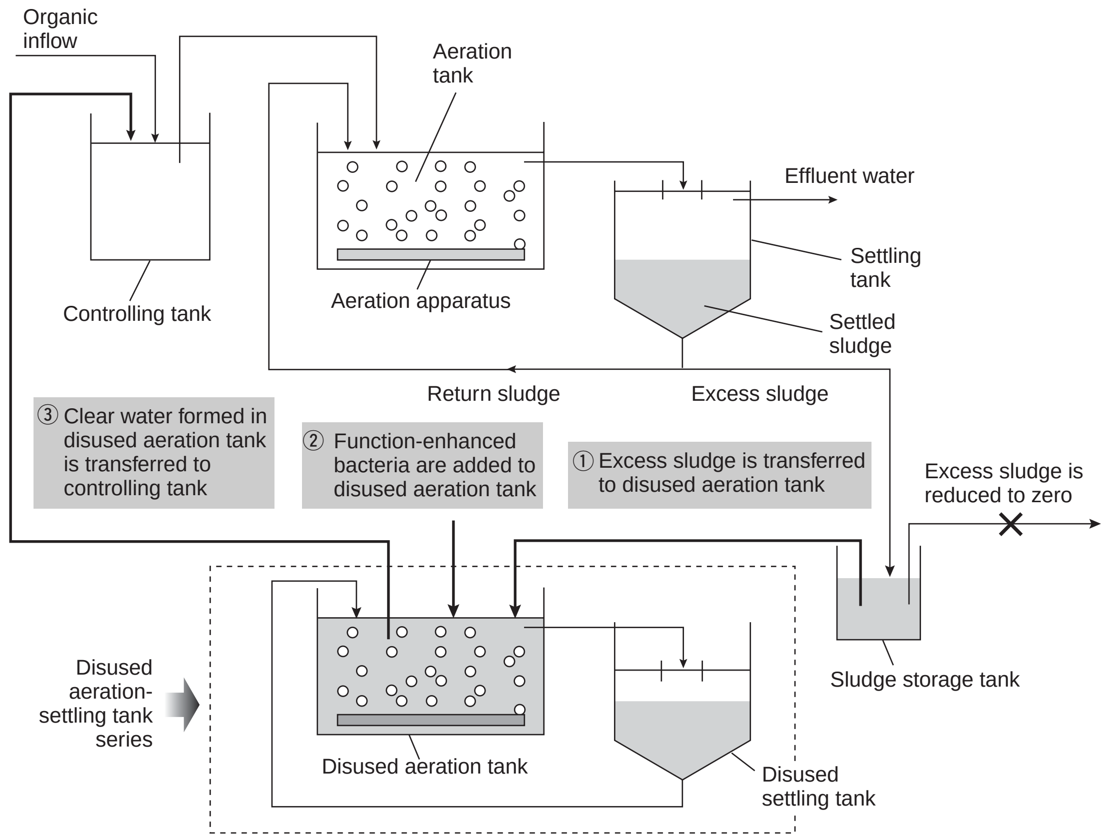

Figure 9
Treatment flow in System 2 septic tank of Nasu plant for function-enhanced bacteria method.

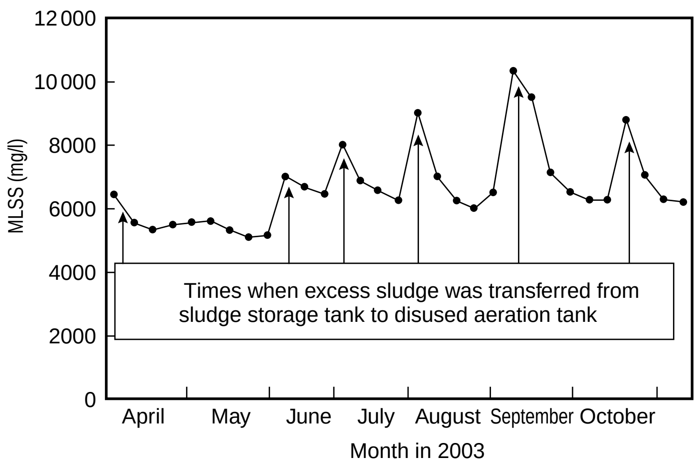

Figure 10
Change in MLSS in disused aeration tank of System 2 septic tank of Nasu plant.

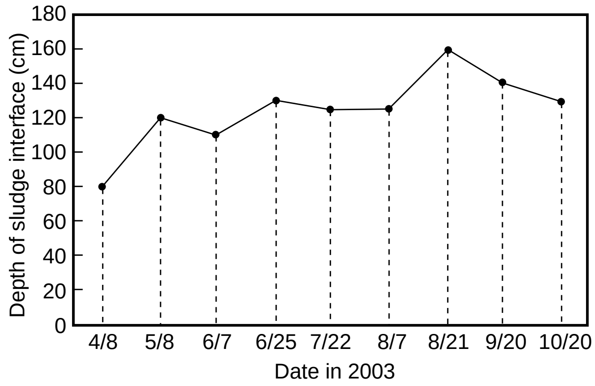

Figure 11
Change in depth of sludge interface in System 2 settling tank of Nasu plant.

Application of the method resulted in a 63% increase in unit cost from April to June and a 4% reduction from July to September.

The reason for the high cost at the early stage of the application was that a greater amount of bacteria had to be added to make them the dominant species. When the system reached a steady state, the cost was nearly the same as it was before the application.

6) Expansion of the method to the entire Fujitsu Group

Based on the tentative half-year application to the tanks at the Nasu plant, this method was judged practicable for achieving zero sludge emissions. Since then, this method has been regularly used at the Nasu plant. So far, this method has been used to resolve about 350 m^3 of sludge at the plant, and no sludge has been discharged from it.

Before October 2003, the sludge emitted from 14 other plants in the Fujitsu Group was disposed of. Since then, this method has been successively expanded to these 14 plants, and so far, it has resolved a total of about 1500 m^3 of sludge with no discharge. Based on this result, the target of zero sludge emissions in the Group has been achieved.

5. Conclusion

One of the targets of the Fujitsu Environmental Program (Stage Ⅲ), which was started in 2001, is zero emissions of waste, which is defined as zero disposal of waste outside of a company. To help achieve this target, we tackled the problem of reducing the disposal of sludge discharged from septic tanks to zero. To this end, we investigated a method of using function-enhanced bacteria that can reduce sludge to zero with better cost-performance than other methods. We then tentatively applied this method to the septic tanks at Fujitsu's Nasu plant for half a year, where emitted sludge was previously disposed of.

We demonstrated that the method achieved zero sludge emissions, the quality of activated sludge was kept in good condition, and there was no difference in the quality of the treated water compared to the previously used system. This method, having being judged to be practicable, has been expanded to 14 other plants in the Fujitsu Group that previously disposed of their emitted sludge. Since the application of this method, there has been no discharge of sludge from these plants. In total, we have used this method to resolve about 1500 m^3 of sludge. As a result, disposal of sludge from the Fujitsu Group has become zero.

This big reduction in environmental burden throughout the entire Group using a single method is considered to be a first in Japan in the field of treating sludge generated from septic tanks. This activity has also contributed much to the achievement of zero emissions in the Fujitsu Group.

Before this method can be put to wider use, the following must be done:

1) An operational method must be established to stably reduce the excess sludge to zero. There are various factors that change the influent loading in a septic tank, for example, changes in the number of employees, changes in the quality of the organic inflow, and seasonal changes in water temperature. These changes inevitably affect the quantity and density of the activated sludge. Therefore, the status of septic tanks must be stably controlled to enable effective treatment of or-

ganic drainage regardless of changes in influx loading. In addition, to consistently accomplish zero sludge emissions using this method, optimal control of the added bacteria is necessary. Therefore, a stricter method of controlling the operation of septic tanks is needed, both to guarantee stable formation of the activated sludge and reduce the excess sludge to zero. In order to guarantee stable operation of septic tanks, we plan to write a manual that will describe the optimal amounts of added bacteria for various conditions, criteria for judging whether treated sludge is normal, measures for overcoming operational problems, and other information.

2) The cost of the function-enhanced bacteria must be reduced. Before the application of the bacterial method, excess sludge was disposed of at public facilities at fairly low cost, especially in rural areas. On the other hand, the cost of the bacteria cannot easily be reduced because they are very difficult to mass-produce. To achieve a cost reduction, we plan to optimize the quantity of added bacteria for each septic tank; that is, find the smallest possible quantity that guarantees zero sludge emissions.

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