New Wastewater Treatment Solution Using *Bacillus*

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ABSTRACT

Fuji Electric has developed a new wastewater treatment solution using *Bacillus*. This solution uses special *Bacillus* that we found suitable for wastewater treatment among a number of such species existing in nature. This allows existing wastewater treatment facilities to reduce the electric power cost for aeration and sludge disposal cost without the need for large-scale modification or extension of the facilities. The sludge-less wastewater treatment system has a magnetic separator that separates sludge by magnetic force, achieving significant space-saving and better treatment performance. In an application example for factory wastewater treatment, the new wastewater treatment solution reduced the running cost by 20%, and the sludge-less wastewater treatment, by 25%.

1. Introduction

It is mandatory to treat wastewater from factories and workplaces properly according to stringent wastewater standards based on the "Water Pollution Prevention Act" and "more stringent standards" specified in ordinances of local governments. Although the conventional activated sludge process is widely used for wastewater treatment, it has a high running cost such as the costs of electricity and sludge disposal.

In order to reduce such running cost in food, beverage and chemical plants, Fuji Electric has developed a new wastewater treatment solution using *Bacillus*.

2. Wastewater Treatment and Running Cost

Biological treatments, the conventional activated sludge process in particular, have been used widely for the treatment of organic wastewater in various plants because they are easy to maintain and manage. Figure 1 shows the basic flow of wastewater treatment and an example of the facility. The conventional activated sludge process is a method to use microorganisms suspended in wastewater to take in the pollutants and purify the wastewater, and then have the microorganisms settle and remove them. Since the microorganisms require oxygen to decompose the pollutants they take in, air injection with a blower (aeration) is necessary for the waste water to increase concentration of the dissolved oxygen in the wastewater to the level required by the microorganisms. Moreover, the microorganisms decompose the pollutants to grow and propagate, and they need to discharge the agglomeration of

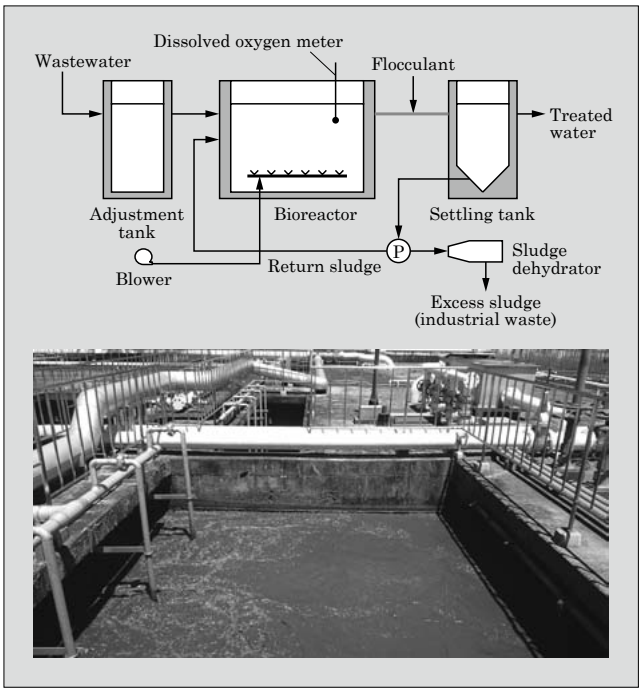

Fig.1 Basic flow of wastewater treatment and example of facility

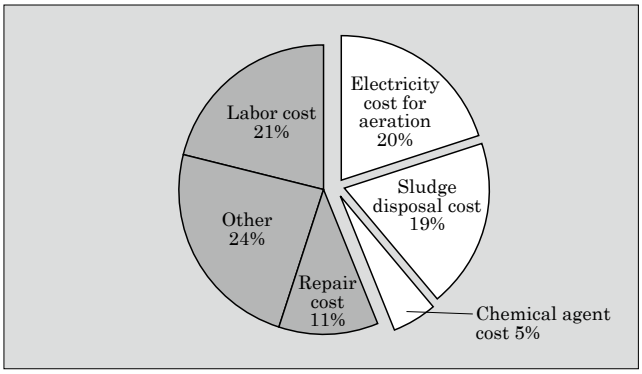

Fig.2 Example of running cost for wastewater treatment

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excessively propagated microorganisms (excess sludge) out of the system. The discharged excess sludge is treated as industrial waste.

Figure 2 shows an example of the running cost for wastewater treatment in a plant. The electricity cost for aeration and sludge disposal cost (industrial waste disposal cost) account for a large portion of the running cost for wastewater treatment, around 40%.

3. Wastewater Treatment Using *Bacillus*

There are many *Bacillus**1 species existing in nature and some of them have a high wastewater purification ability to decompose highly concentrated organic substances in a short time and also secrete a large quantity of enzymes that can decompose excess sludge. By finding such a species and using it as *Bacillus* for wastewater treatment, Fuji Electric has managed to both reduce running cost and improve the performance of wastewater treatment.

3.1 Features

(1) Reduced running cost
  (a) Electricity cost for aeration can be reduced by 10% to 40% compared with conventional methods.
  (b) Sludge disposal cost can be reduced by 20% to 40% compared with conventional methods.
  (c) Chemical agent cost can be reduced by 10% to 20% compared with conventional methods.

(2) Improved treatment performance
  (a) The capacity for addressing fluctuations in the quality of the wastewater that flows into the facility can be expanded. This provides a better treatment performance compared with conventional methods and improves water quality.
  (b) Foul odors can be suppressed to improve the surrounding environment and work environment.

(3) Easy introduction, maintenance and management
  (a) Large-scale capital investment is unnecessary because the wastewater treatment using *Bacillus* can reduce sludge production and aeration volume without the need for alteration or extension to existing wastewater treatment facilities and equipment.
  (b) The operation starts by pouring *Bacillus* into an existing bioreactor. This is required for the first time only. After that, the operator needs only to add a small amount of chemical agent (activator) daily in order to retain the dominance and performance of the *Bacillus*.
  (c) Retaining the number of *Bacillus* that exceeds about 100 times the initial number (*Bacillus* dominant state) can maintain the effects of reducing excess sludge and aeration volume while preserving the water quality.
  (d) The adjustment period is 2 to 3 months, during which the aeration volume and sludge concentration should be adjusted to ensure *Bacillus* are dominant.

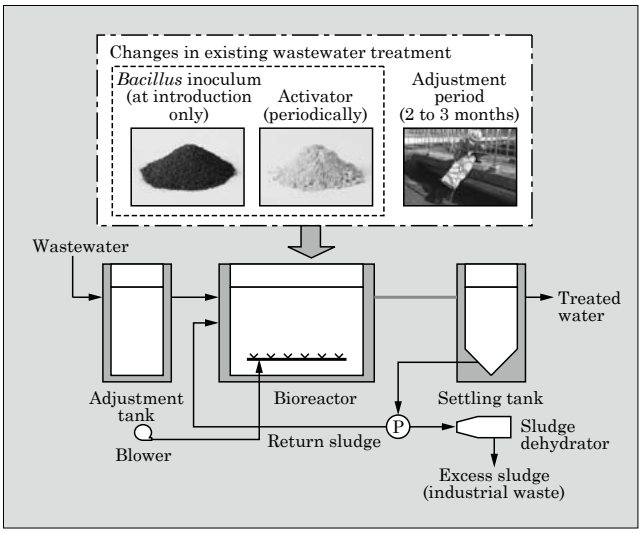

Fig.3 General process of wastewater treatment using *Bacillus*

Figure 3 shows a typical process of the wastewater treatment using *Bacillus*. The major items to be adjusted are aeration volume and the amount of return sludge.

3.2 Effects of *Bacillus* in wastewater treatment

(1) *Bacillus* for wastewater treatment

Bacillus is one of facultative anaerobic bacteria*2 that can live with a low amount of dissolved oxygen*3. The conventional activated sludge process uses *Bacillus* existing extensively in activated sludge. The *Bacillus* for wastewater treatment can purify pollution components with less amount of oxygen. This allows the blower to operate with lower air volume, resulting in a reduction in the electricity cost for aeration.

(2) Activator

Adding an activator consisting mainly of minerals such as silicon, iron and magnesium to the *Bacillus* for wastewater treatment promotes the propagation of the bacteria, so that it retains its dominance, resulting in stable purification performance. The activator for wastewater treatment enhances the ability of the *Bacillus* for wastewater treatment to secrete enzymes which decompose proteins, carbohydrates and other sludge components. This promotes the decomposition

*1: *Bacillus*: Refer to "Supplemental Explanation" on page 60.

*2: Facultative anaerobic bacteria: Generic term referring to bacteria that can live with or without oxygen, or more specifically that can live with oxygen in a low concentration.

*3: Dissolved oxygen: Oxygen that is dissolved in water

of excess sludge and decreases the amount of sludge production.

Moreover, the *Bacillus* for wastewater treatment has a property of increasing the activity of a proteolytic enzyme (secretion) by about 30 times in response to the addition of the activator. This activity is about 10 times higher than those of other *Bacillus* species (see Fig. 4). The *Bacillus* for wastewater treatment has another property of increasing the activity of a carbohydrate-degrading enzyme by about 25 times in response to the addition of the activator. This activity is about 3 times higher than those of other *Bacillus* species (see Fig. 5). These properties contribute to the improvement of the abilities of decomposing the pollution components and purifying sludge components in wastewater compared with conventional methods.

(3) Sludge reduction

Fuji Electric has found out that the ability of the *Bacillus* for wastewater treatment to reduce excess sludge relies on the working of the enzymes secreted by the bacteria.

Figure 6 is a graph showing the comparison of the remaining sludge before and after the enzymes of the *Bacillus* for wastewater treatment (sterilized culture liquid) were added to the excess sludge of a wastewater treatment facility using the conventional activated sludge process. Adding the enzymes promoted the decomposition and removal of about 40% of the sludge. This explains how the enzymes could reduce the amount of sludge.

(4) Improved sludge settlement and odor removal

The *Bacillus* for wastewater treatment has high flocculation and cohesion, so that it can improve sludge settlement.

Figure 7 shows a comparison of sludge volumes (SV, rate of activated sludge settlement) in 30 minutes between the sludge treated with *Bacillus* for wastewater treatment and the sludge treated with conventional activated sludge process. The sludge treated with *Bacillus* for wastewater treatment settles faster than the sludge treated with the conventional activated sludge process. This makes solid-liquid separation easier and reduces discharge of the sludge.

Moreover, the *Bacillus* for wastewater treatment can remove odors by decomposing foul odor components such as hydrogen sulfide and ammonium.

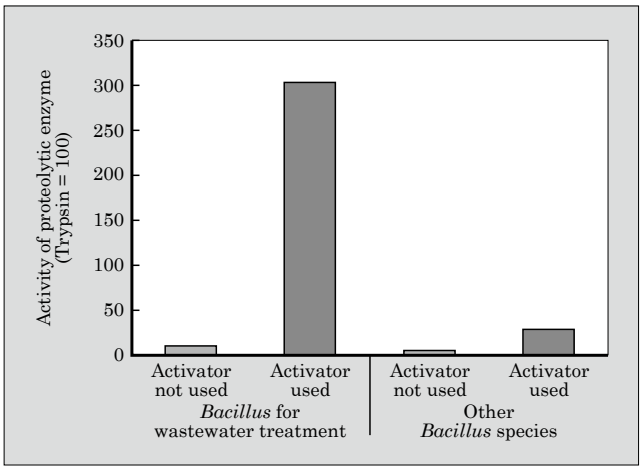

Fig.4 Activity of proteolytic enzyme

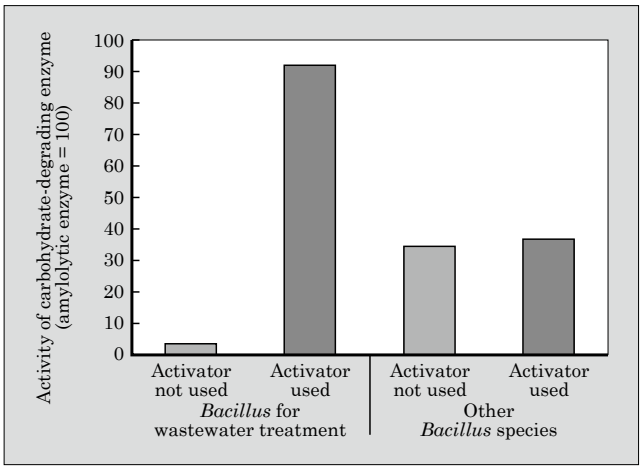

Fig.5 Activity of carbohydrate-degrading enzyme

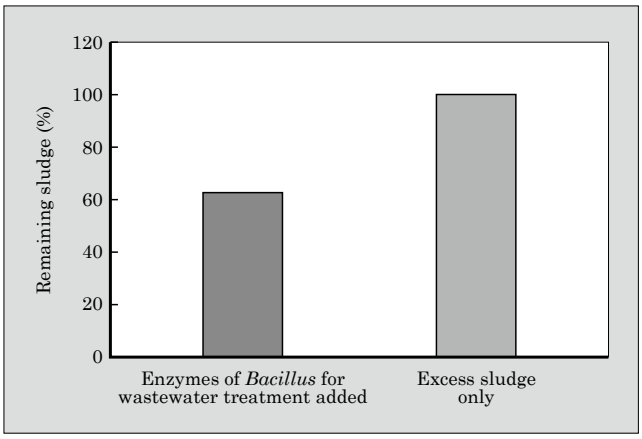

Fig.6 Sludge decomposition with enzymes of *Bacillus* for wastewater treatment

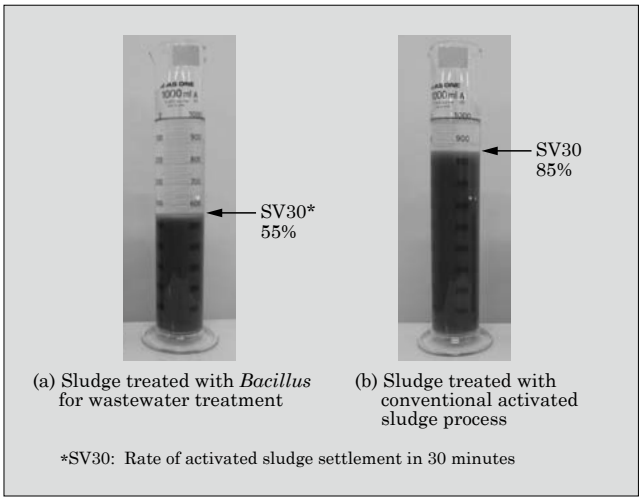

Fig.7 Improvement of sludge settlement due to use of *Bacillus* for wastewater treatment

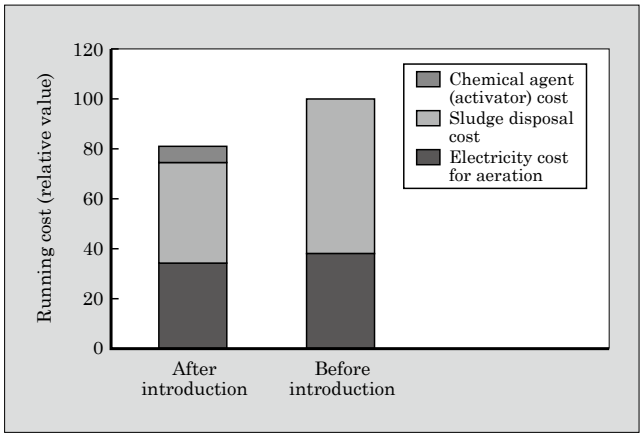

Fig.8 Example of introducing *Bacillus* for wastewater treatment

3.3 Application example

Fuji Electric has applied the wastewater treatment using the *Bacillus* for wastewater treatment to a factory of company A. This factory has introduced the conventional activated sludge process and the amount of wastewater is 1,500 m^3/day. The purpose is to reduce the sludge disposal cost in the running cost for wastewater treatment.

(1) Introduction method

For the introduction, we did not make any alteration or extension to the existing wastewater equipment but only poured an inoculum of the *Bacillus* for wastewater treatment. A specified amount of activator was added to the bioreactor every day. The aeration volume and the amounts of return sludge and waste sludge were adjusted during the 3-month adjustment period. In this adjustment period, we confirmed that the number of *Bacillus* for wastewater treatment increased to about 100 times the initial number, and it reached its dominant state.

(2) Introduction effects

Using the *Bacillus* for wastewater treatment reduced the electricity cost for aeration and sludge disposal cost by 10% and 35% respectively compared with the costs before the introduction. After subtracting the increased cost of the activator added every day, the running cost for the entire wastewater treatment was reduced by about 20% (see Fig. 8).

4. Sludge-Less Wastewater Treatment System

Using the *Bacillus* for wastewater treatment together with a magnetic separator makes it possible to construct a sludge-less wastewater treatment system that produces almost no excess sludge. Figure 9 shows the process of this system. When a magnetic separator is added to the wastewater treatment using *Bacillus* shown in Fig. 3, the settling tank and return sludge can be eliminated and the sludge dehydrator is also unnecessary.

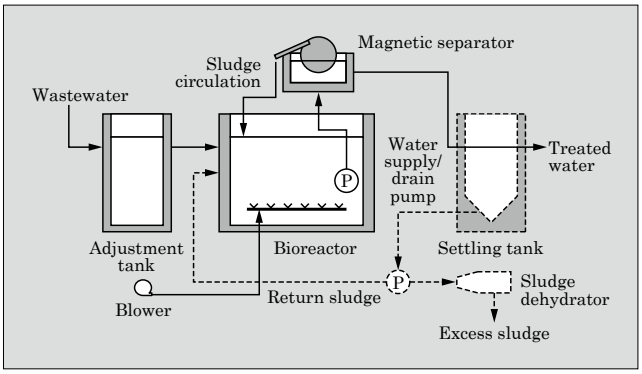

Fig.9 Process of sludge-less wastewater treatment system

4.1 Features

This system is targeted mainly at workplaces that have to upgrade, newly construct or extend their wastewater treatment facilities due to increased wastewater and pollutants caused by increased production or plant integration. It can satisfy the need for building a facility in an extremely tight space or for suppressing the increase in running cost for wastewater treatment. The system is characterized by the following features compared with conventional systems using the conventional activated sludge process.

(1) Effects on running costs
  (a) Sludge disposal cost can be reduced by 90% or more. No organic sludge is produced, and the system only requires inorganic sediments to be disposed of several times a year.
  (b) There is no electricity cost for aeration for sludge treatment.
  (c) There is no chemical agent cost for sludge treatment.

(2) Improved ability of purifying pollution components

The system can handle a pollutant concentration 3 times higher than that of the conventional system.

(3) Reduced initial investment
  (a) A settling tank is unnecessary.
  (b) The capacity of the bioreactor can be reduced one half to one third.
  (c) A sludge dehydrator is unnecessary.

Since the magnetic separator separates the sludge into solid and liquid, a settling tank used in conventional methods becomes no longer necessary. Since no organic sludge is produced, a sludge dehydrator is unnecessary. Inorganic sludge, however, should be removed several times a year.

(4) Space saving

The space occupied by wastewater treatment equipment can be reduced to half compared with conventional systems.

(5) Improved treatment performance
  (a) The nitrogen removal rate is 90% or more.
  (b) Foul odors can be suppressed to improve the surrounding environment and work environ-

ment.

4.2 System construction

(1) Calculating sludge production

As shown in equation (1), the sludge production during wastewater treatment is calculated by multiplying the biochemical oxygen demand (*BOD*) and suspended solid (*SS*) by the amount of wastewater and their sludge conversion rates respectively, adding the products to obtain the amount of increased sludge (propagated microorganisms), and then subtracting the amount of decreased sludge due to sludge self-digestion and the decomposition by enzymes from the sum.

As described above, the *Bacillus* used in this system secretes a large quantity of enzymes that decompose sludge. The amount of these enzymes increases with the concentration of the *Bacillus*. Consequently, when the sludge concentration (mixed liquor suspended solids [MLSS]) in the bioreactor is increased to enhance the concentration of the *Bacillus* of this system, the amount of sludge decomposing enzymes secreted by the *Bacillus* increases to effectively treat the sludge that has increased due to the biological treatment of pollutants. This promotes the decomposition of the sludge, allowing the operation to produces no sludge.

$$W = A \times BOD \times Q + B \times SS \times Q - C \times MLSS \times V \cdots\cdots (1)$$

W: Sludge production (kg/d)
BOD: Biochemical oxygen demand (kg/m^3)
SS: Suspended solid (kg/m^3)
$MLSS$: Mixed liquor suspended solids (kg/m^3)
Q: Amount of wastewater (m^3/d)
V: Capacity of bioreactor (m^3)
A: BOD sludge conversion rate (%)
B: SS sludge conversion rate (%)
C: Self-digestion rate (%)

(2) Solid-liquid separation of sludge

The surfaces of the bacterial bodies in the activated sludge are negatively charged and magnetic powder (magnetite, Fe_3O_4) is positively charged. Consequently, when mixed, they adhere to each other and the activated sludge is magnetized.

As shown in Fig. 10, when magnetic powder is added to the activated sludge and the sludge is stirred, the solids in the sludge and the powder quickly adhere to each other. This makes the activated sludge become magnetic activated sludge that allows for quick and efficient solid-liquid separation with a magnetic force.

(3) Magnetic separator

Fuji Electric has developed a magnetic separator capable of continuously separating solids and liquids in the magnetic activated sludge with a magnetic force and established a wastewater treatment process without a need for final settlement. Unlike conventional solid-liquid separation based on gravity settlement, sludge is forced to concentrate, so that the system can retain a high concentration of the sludge in the bioreactor. This strikes a balance between the increase in and self-digestion of the sludge to operate without producing sludge.

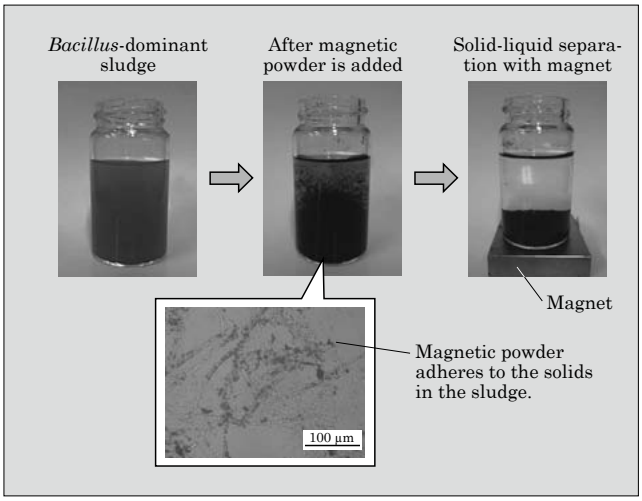

Fig.10 Magnetic activated sludge

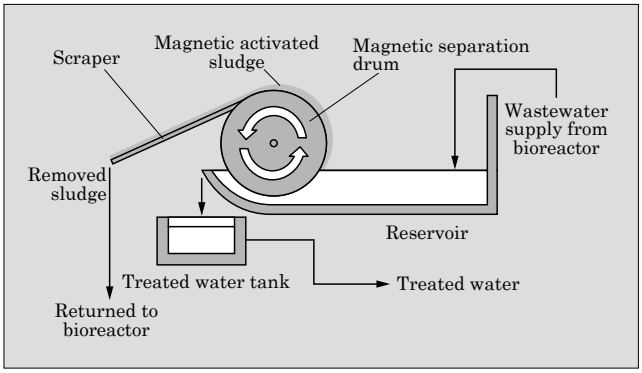

Fig.11 Schematic diagram of magnetic separator

Figure 11 shows a schematic diagram of the magnetic separator used in the system. The magnetic activated sludge in the bioreactor is pumped up and sent to the reservoir of the magnetic separator. A magnetic drum for magnetic separation is turning inside the reservoir. When the magnetic activated sludge passes by the drum, it adheres to it. The sludge is later removed with a scraper and returned to the bioreactor.

(4) Improved purification ability

Since the system can ensure a high concentration of the activated sludge is retained in the bioreactor, the pollutant purification ability of the bioreactor per unit volume can be increased to about 3 times.

4.3 Application example

Fuji Electric has applied this system to the factory of food manufacturing company B. This factory has introduced the conventional activated sludge process and the amount of wastewater is 2,000 m^3/day. The purpose is to reduce the sludge disposal cost and to address the increased wastewater load due to increased production.

(1) Introduction procedure

For the introduction, we installed a magnetic separator and a pump that feeds magnetic activated sludge to the separator. We poured an inoculum of the *Bacillus* and magnetic powder into the bioreactor of the system. A specified amount of activator was added to the bioreactor every day.

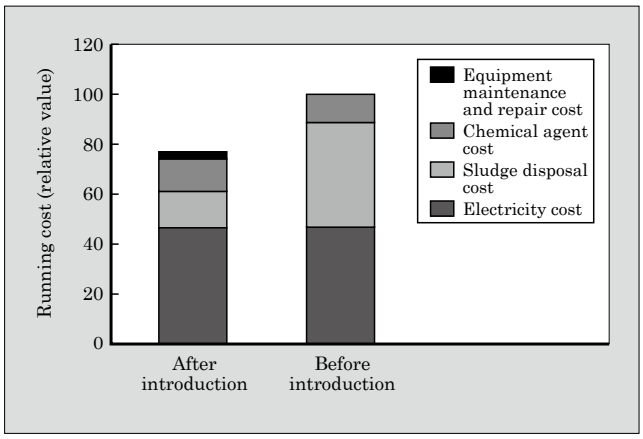

Fig.12 Introduction effects of sludge-less wastewater treatment system

(2) Introduction effects

This system reduced the sludge produced through biological treatment by 90% compared with conventional methods, and the amount of total sludge production including the sludge produced in pretreatment by about 66%. The system can treat 3 times more pollutants in wastewater than the conventional amount. After subtracting the increased costs of the chemical agent (activator) added every day, supplementary magnetic powder, and maintenance and repair of the magnetic separator, the running cost for the entire wastewater treatment was reduced by about 25% (see Fig. 12).

5. Postscript

This paper described a new wastewater treatment solution using *Bacillus* that targets wastewater treatment equipment in food, beverage and chemical plants. By expanding the applications of this solution, Fuji Electric intends to help reduce the operation and maintenance costs for wastewater treatment and lessen environmental loads.

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