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Biological Treatment of High-pH and Sulfur Compound-Contaminated Waste Water

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Abstract:

High-pH and sulfur compound-contaminated waste water is high not only in pH but also in chemical oxygen demand (COD). Biological treatment technology was developed to economically treat this waste water. Technology was first established for sulfur-oxidizing bacteria active in the neutral pH region. Using the cultivated bacteria, a series of research and development work was undertaken up to the pilot plant stage. Based on the R&D results, a feasibility study was performed to confirm that biological treatment is more economical than chemical treatment, and a commercial biological treatment plant was constructed.

1. Introduction

Bacteria are extensively used for treating various types of industrial waste water and domestic sewage. In the steelmaking process involving the blast furnace, ammonia liquor from coke plants is treated by the activated sludge method. In biological waste water treatment, bacteria catalytically work to promote the reactions involved and remove pollutants. In particular, many of the components of chemical oxygen demand (COD) are efficiently oxidized by bacteria. Compared with chemical oxidation by ozone and the like, biological treatment is very low in operating cost and is often economical as far as the total treatment cost, including the equipment expenses, is concerned. Biological waste water treatment also has the advantage that harmful substances such as organic chlorine compounds are not readily produced during treatment.

This paper reports the technology developed for biologically treating high-pH and sulfur compound-contaminated waste water by taking advantage of the features noted above.

2. Biological Treatment of High-pH and Sulfur Compound-Contaminated Waste Water

2.1 High-pH and sulfur compound-contaminated waste water

High-pH and sulfur compound-contaminated waste water is typically discharged from equipment for removing hydrogen sulfide gas by using sodium hydroxide as an absorbent. This waste water is high not only in pH (generally, pH > 10) but also in COD, because sulfur compounds (such as sodium sulfide and sodium thiosulfate) other than sulfates are measured as COD. Before discharging the waste water into a common water way, it is necessary to neutralize the pH, oxidize the sulfur compounds, and reduce COD levels.

2.2 Oxidation of sulfur compounds by bacteria

Sulfur compounds in water are difficult to oxidize by aeration

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alone, but can be oxidized by utilizing sulfur-oxidizing bacteria living in sulfur springs and the like. For example, Thiobacillus thiooxidans is known to oxidize inorganic sulfur compounds in the presence of water as expressed by the following reaction equations[1]:

$$4S_2O_3^{2-} + O_2 + 2H_2O^{2-} \rightarrow 2S_4O_6^{2-} + 4OH^- \quad \cdots\cdots(1)$$

$$+)\ 2S_4O_6^{2-} + 7O_2 + 6H_2O \rightarrow 8SO_4^{2-} + 12H^+ \quad \cdots\cdots(2)$$

$$4S_2O_3^{2-} + 8O_2 + 4H_2O \rightarrow 8SO_4^{2-} + 8H^+ \quad \cdots\cdots(3)$$

Thiobacillus thiooxidans can assimilate with carbon dioxide by utilizing the energy produced when it oxidizes sulfur compounds. It accordingly multiplies in waste water in the absence of organic matter and is considered to be suitable for treating high-pH and sulfur compound-contaminated waste water.

Thiobacillus thiooxidans is active in acidity of pH 2 to 3.5, but its activity dramatically declines when the pH exceeds 4. To treat the high-pH and sulfur compound-contaminated waste water with Thiobacillus thiooxidans, the pH must be adjusted to about 3 by using such additives that enable Thiobacillus thiooxidans to properly oxidize the sulfur compounds. The use of Thiobacillus thiooxidans makes biological treatment economically unviable for the following reasons:

- The sulfur compound oxidation water tank must be made acid resistant.
- Hydrogen sulfide is released into the air when waste water has a high concentration of sulfide, creating the need for equipment to capture this hydrogen sulfide.
- Acid consumption increases when lowering the pH of the waste water to about 3.
- To discharge the treated water, the pH must be readjusted to between 6 to 8, requiring reneutralization with alkalies.

To economically treat the high-pH and sulfur compound-contaminated waste water, the sulfur compounds must be oxidized in a neutral or alkaline condition. To this end, it is indispensable to use high-activity sulfur-oxidizing bacteria in the neutral or alkaline condition.

2.3 Experiments to locate high-activity sulfur-oxidizing bacteria in neutral pH region

2.3.1 Sludge in biological deodorizing tower

In biological deodorization at conventional sewage works, sulfur compounds are oxidized in a deodorizing tower of approximately neutral pH. Postulating that sulfur-oxidizing bacteria suitable for treating the high-pH and sulfur compound-contaminated waste water may be present in the deodorizing tower, the authors conducted a thiosulfuric acid oxidation experiment on the sludge taken from the deodorizing tower.

(1) Experimental method

A diluted sulfuric acid or sodium hydroxide solution was added to 300 mL of a culture medium composed as shown in **Table 1**. The pH was adjusted to 2, 3, 4, 5, 6, 7 or 8, and 10 mL of sulfur-oxidizing bacteria extract solution was added. The mixture was maintained at 30°C and shaken. Its $S_2O_3^{2-}$ concentration was measured once per day. The sulfur-oxidizing bacteria extract solution was prepared as described below. Five grams of the sludge taken from the biological deodorizing tower was added to 100 mL of the solution of the composition given in **Table 1** and with less sodium thiosulfate. The mixture was maintained at 30°C, shaken for 1 h, and filtered with 5A filter paper. The filtrate was used as the extract solution.

Table 1 Composition of culture medium

Sodium thiosulfate	5g*	Ammonium chloride	0.1 g
Monobasic potassium phosphate	3g	Calcium chloride	0.25 g
Magnesium chloride	0.1g	Distilled water	1L

*: pentahydrate ($S_2O_3^{2-}$=2,258 mg/L)

(2) Experimental results

The number of days for the oxidation of thiosulfuric acid to be completed (or for the $S_2O_3^{2-}$ concentration of the culture medium to drop below 50 mg/L) is shown in **Fig. 1**.

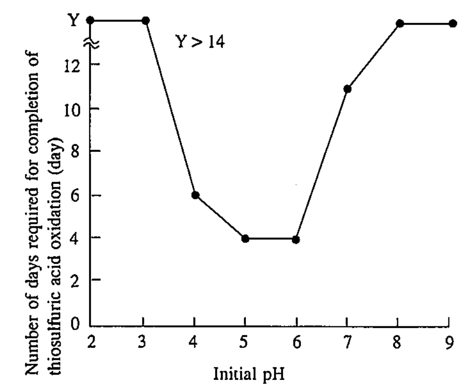

Fig. 1 Oxidation of thiosulfuric acid by sludge in biological deodorizing tower

(3) Discussion

- It was confirmed that bacteria capable of oxidizing thiosulfuric acid over a wide pH range of 4 to 7 (see **Photo 1**) were present in the sludge taken from the biological deodorizing tower and that these bacteria are highly active at a close to neutral pH of 5 to 6. When their characteristics were compared with the available literature[2], it was found that the bacteria were not Thiobacillus thiooxidans but did belong to the Thiobacillus genus.
- Since sewage treatment activated sludge was used as seed sludge in the biological deodorizing tower, the sulfur-oxidizing bacteria were considered to grow in the sewage treatment activated sludge.

2.3.2 Sewage treatment activated sludge

Since highly active sulfur-oxidizing bacteria at close to neutral

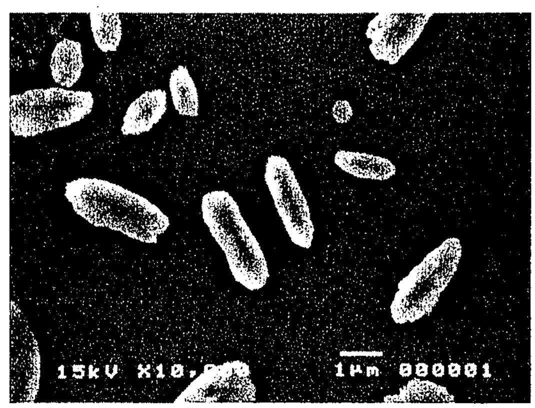

Photo 1 Electron micrograph of sulfur-oxidizing bacteria

pH were considered to be present in the sewage treatment activated sludge, a thiosulfuric acid oxidation experiment was carried out using the sewage treatment activated sludge.

(1) Experimental method

The experimental method described in Section 2.3.1 was employed, except that the pH was adjusted to 4, 5 or 6 and that 10 mL of the supernatant liquid from the sewage treatment activated sludge was added.

(2) Experimental results

The change in the $S_2O_3^{2-}$ concentration of the culture medium is shown in **Fig. 2**.

(3) Discussion

- As expected, high-activity sulfur-oxidizing bacteria in the neutral pH region were present in the sewage treatment activated sludge.
- There is a high possibility that should sulfur-oxidizing bacteria be acclimatized to the sewage treatment activated sludge, large-scale cultivation can be undertaken.

2.4 Acclimatization experiments for sewage treatment activated sludge[3]

Identification experiments confirmed the presence of high activity sulfur-oxidizing bacteria in the neutral pH region in the sewage treatment activated sludge. An experiment was then conducted to acclimatize the bacteria.

(1) Experimental method

Sewage treatment activated sludge with MLSS ≈ 1,500 mg/L (MLSS is short for mixed-liquor suspended solids and used as a simple index of the sulfur-oxidizing bacteria concentration) was

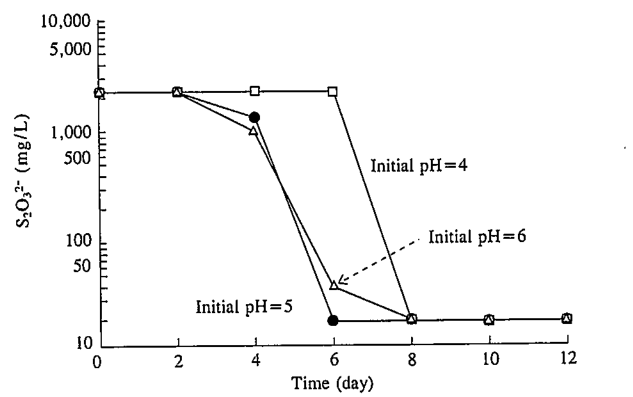

Fig. 2 Oxidation of thiosulfuric acid by sewage treatment activated sludge

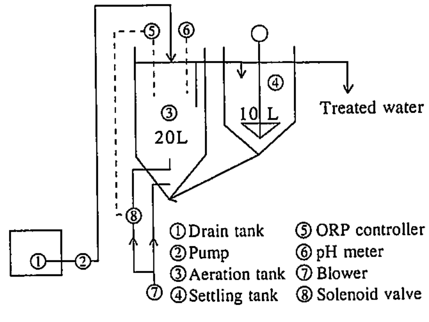

Fig. 3 Bench-level experimental apparatus

added to the bench-level experimental apparatus shown in **Fig. 3**. The pH of artificial waste water composed as shown in **Table 2** was adjusted to about 12. The artificial waste water was supplied to the aeration tank at such a rate that its aeration time was 8 h. The pH of the solution in the aeration tank was kept between 5 and 7, the aeration rate was 5 L/min, and the water temperature was 20°C.

(2) Experimental results

The $S_2O_3^{2-}$ concentration, COD, MLSS, and oxidation-reduction potential (ORP) with respect to the Ag/AgCl standard electrode during the acclimatization period are shown in **Figs. 4** to **7**.

(3) Discussion

- When the sewage treatment activated sludge was acclima-

Table 2 Composition of artificial water

Sodium thiosulfate	1g*	Ammonium chloride	0.02g
Monobasic potassium phosphate	0.6g	Calcium chloride	0.05g
Magnesium chloride	0.02g	Distilled water	1L

* : pentahydrate ($S_2O_3^{2-}$ = 452 mg/L)

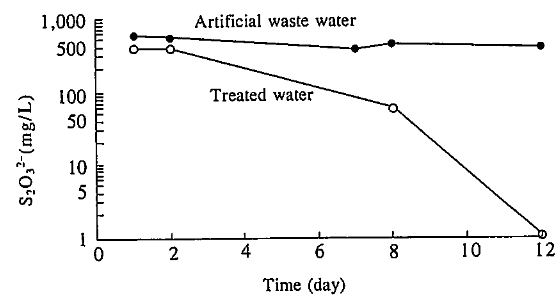

Fig. 4 $S_2O_3^{2-}$ during acclimatization period in bench-level experiment

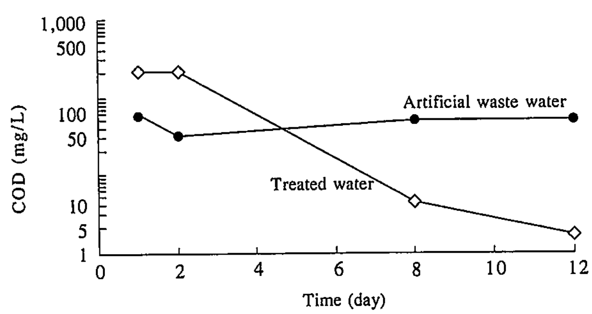

Fig. 5 COD during acclimatization period in bench-level experiment

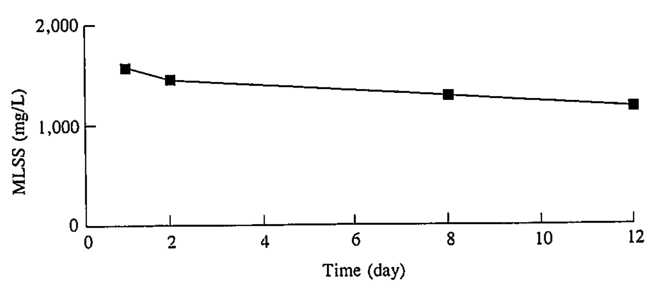

Fig. 6 MLSS during acclimatization period in bench-level experiment

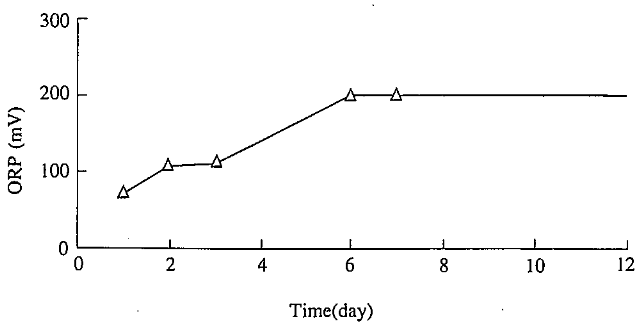

Fig. 7 ORP during acclimatization period in bench-level experiment

tized in artificial waste water containing thiosulfuric acid ions, the thiosulfuric acid ions were almost completely oxidized after 12 days. This means that the acclimatization period of the sulfur-oxidizing bacteria is 10 plus days — a practical level.

• For the first few days of acclimatization, the COD was higher in the treated water than in the artificial waste water. This is probably because microorganisms other than the sulfur-oxidizing bacteria in the sewage treatment activated sludge, for example, heterotrophic bacteria that biodegrade organic matter, were carried by the treated water and became a source of COD.

• The outflow of the above-mentioned bacteria initially reduced the MLSS, and the MLSS did not rise thereafter. This fact suggested that the sulfur-oxidizing bacteria multiplication rate was considerably low.

• The ORP in the aeration tank gradually rose, reached +200 mV on the sixth day, and was stable on the seventh day. The aeration rate was thus controlled to maintain the ORP of +200 mV on the seventh and subsequent days. Under this condition, $S_2O_3^{2-}$ was smoothly oxidized. This means that an appropriate ORP near pH 6 is about +200 mV.

2.5 Continuous bench-level treatment experiments[4)]

2.5.1 Reduction of aeration time in artificial waste water

The acclimatization experiment confirmed that about 500 mg/L of thiosulfuric acid ions can be oxidized in 8 h or less. An aeration time reduction experiment was then conducted to determine the necessary oxidation time of thiosulfuric acid ions.

(1) Experimental method

Time in the aeration tank was gradually shortened from 8 h to 6, 4, 3, and 2 h, and the quality of the treated water was measured. The target COD for the treated water was set at a maximum of 20 mg/L.

(2) Experimental results

The experimental results are shown in **Fig. 8**.

(3) Discussion

• When 400 to 500 mg/L of thiosulfuric acid ions were oxidized by the sulfur-oxidizing bacteria acclimatized in the sewage treatment activated sludge, the COD of the treated water was practically stabilized at 20 mg/L or less when aerated for 3 h. When aerated for 2 h, the COD of the treated water exceeded 20 mg/L. For this reason, 3 hours of aeration was taken as the necessary oxidation time.

• If the necessary oxidation time is 3 h, there is a high possibility that biological oxidation may be more advantageous than chemical oxidation in terms of the total treatment cost as a sum of the equipment and operating costs.

• Five percent sulfuric acid consumed for neutralization amounted to approximately 2.4 mL per L of artificial waste water. When the artificial waste water was directly neutralized without the sulfur-oxidizing bacteria, the necessary consumption of 5% sulfuric acid was about 17 mL per L of artificial waste water. This difference occurred because the thiosulfuric acid in the artificial waste water was oxidized to become sulfuric acid. The possibility of reducing the consumption of neutralizing agents was confirmed.

2.5.2 Determination of necessary oxidation time in actual waste water

The artificial water experiment confirmed the economics of treatment with sulfur-oxidizing bacteria. An additional experiment was then conducted to determine the necessary oxidation time in actual waste water.

(1) Experimental method

Time in the aeration tank was set at 3 h, and the supply solu-

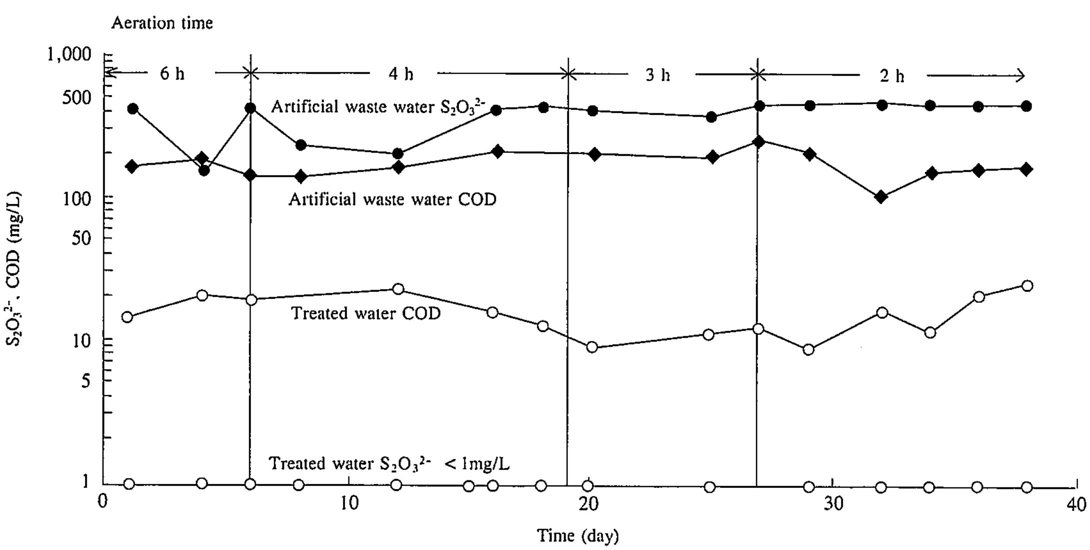

Fig. 8 Results of aeration time reduction experiment

tion was changed to actual waste water composed as given in **Table 3**. The actual waste water contained S^{2-}, which was absent in the artificial waste water. The nitrogen and phosphorus concentrations were far lower than those of the artificial waste water.

(2) Experimental results

The measured water quality values and the change in the ORP in the aeration tank are shown in **Figs. 9** and **10**, respectively.

(3) Discussion

- Immediately after the switch was made from the artificial waste water to the actual waste water, $S_2O_3^{2-}$ and S^{2-} were smoothly oxidized. This fact confirmed that sulfur-oxidizing bacteria acclimatized in the $S_2O_3^{2-}$ water solution can also oxidize S^{2-}.
- About 16 days after the switch, $S_2O_3^{2-}$ and S^{2-} oxidation deteriorated. If the actual waste water contained substances toxic to the sulfur-oxidizing bacteria, the oxidizing ability of the sulfur-oxidizing bacteria should have worsened immediately after the switch to the actual waste water. This unsatisfactory pattern suggests that such toxic substances were not responsible.
- Conversely speaking, the poor oxidation pattern indirectly indicates that the actual waste water contains no toxic substances. Other causes were suspected.
- The ORP gradually diminished after the switch in the type of waste water and sharply declined when $S_2O_3^{2-}$ and S^{2-} increased in the treated water. This was taken as evidence to support the fact that the activity of the sulfur-oxidizing bacteria gradually decreased at first and steeply dropped after some time.
- Judging from the above two findings and from the low nitrogen and phosphorus concentrations in the waste water, the decrease in the oxidizing capacity was attributed to the shortage of nutrient salts required by the sulfur-oxidizing bacteria to maintain their activity and to multiply.

Table 3 Average analyses of actual waste water

pH	12.3	$S_2O_3^{2-}$	232	Kjeldahl-N	2.0
COD	335	S^{2-}	89	T-P	0.08

Units in mg/L except for pH

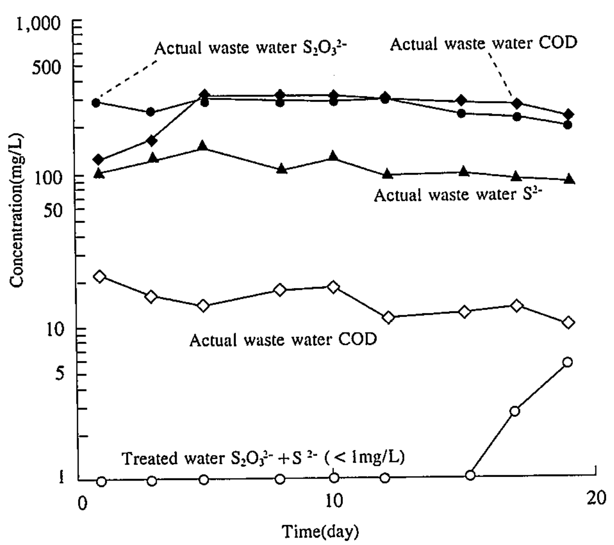

Fig. 9 Results of actual waste water treatment experiment

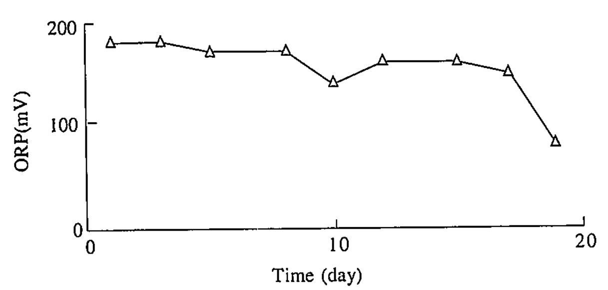

Fig. 10 ORP in aeration tank during actual waste water treatment experiment

2.5.3 Addition of nutrient salts to actual waste water

The actual waste water treatment experiment suggested that a lack of nutrient salts was responsible for the loss of the oxidizing ability. An experiment in which actual waste water was treated with additions of nitrogen and phosphorus was carried out.

(1) Experimental method

Fresh sewage treatment activated sludge was placed in the experimental apparatus shown in **Fig. 3**. Actual waste water was continuously treated with additions of 60 mg/L ammonium chloride and 6 mg/L potassium dihydrogen phosphate.

(2) Experimental results

Fig. 11 shows the water quality, MLSS, and MLVSS. The MLVSS is short for mixed liquor volatile suspended solids and is an index of the sulfur-oxidizing bacteria concentration.

(3) Discussion

- $S_2O_3^{2-}$ and S^{2-} were smoothly oxidized. On the sixth day of the experiment, the COD dropped below 20 mg/L, and the sulfur-oxidizing bacteria acclimatization was completed. This was less than half the acclimatization period of actual waste water without nutrient salt additions recorded in a separate experiment. It was thus confirmed that adding nitrogen and phosphorus as nutrient salts is effective in improving sulfur-oxidizing bacteria activity.
- The suspended solids (SS) in the treated water smoothly decreased, and the MLSS did not increase but decreased. This was ascribed to the low multiplication rate of the sulfur-oxidizing bacteria. Measures for increasing the MLSS were judged to be necessary.

2.5.4 Addition of coagulant

Since the treatment of actual waste water by the addition of nutrient salts indicated the need for increasing the MLSS, experiments in which the actual waste water was treated by the addition of a coagulant were performed successively. Iron salt (ferric chloride), expected to promote oxidization, was used as the coagulant[5].

(1) Experimental method

Under the conditions of the experiment in which the actual waste water was treated by the addition of nutrient salts, iron salt (ferric chloride) was added at a rate of 100 mg/L as Fe at the inlet of the settling tank.

(2) Experimental results

Fig. 11 shows the water quality, MLSS, and MLVSS. (The experimental results on the 29th and subsequent days are shown. The experiment was suspended between the 19th to the 28th day because these days coincided with national holidays in Japan.)

(3) Discussion

- The actual waste water was smoothly treated. The MLSS and MLVSS rose as expected. The effectiveness of the coagulant

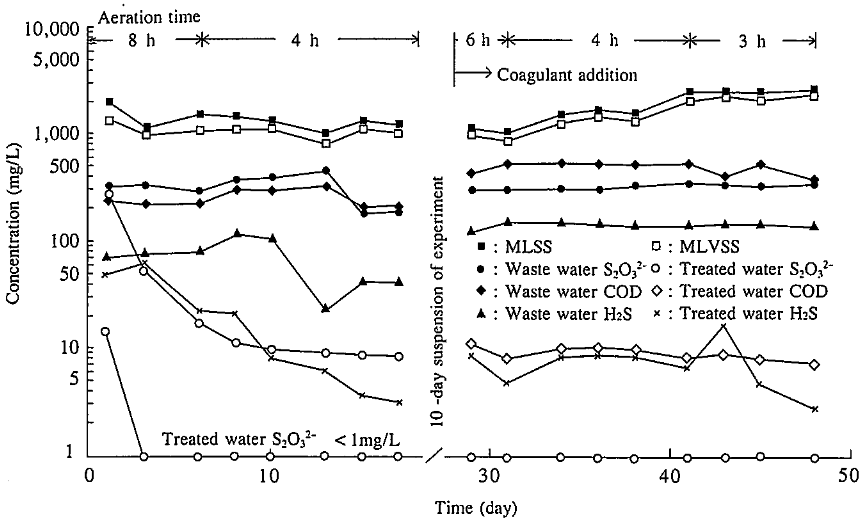

Fig. 11 Results of nutrient salt addition experiment (including those of coagulant addition experiment)

addition was substantiated.

• Since ferric chloride settles as ferric hydroxide, the MLVSS/MLSS ratio was originally expected to decrease, but actually did not change much. This was probably because the addition of iron salt accelerated the proliferation of the sulfur-oxidizing bacteria.

2.5.5 Effect of waste water temperature

To investigate the treating capability of the sulfur-oxidizing bacteria in winter, an experiment was conducted with the temperature of the waste water lowered to 5°C. The following results were obtained:

• The sulfur-oxidizing bacteria have low-temperature resistance, and the loss of their activity at low temperatures is smaller than that of activated sludge and other materials used in sewage treatment.

• It seems unnecessary to heat the raw water or aeration tank when the plant is installed outdoors.

2.6 Pilot plant test

Since the results of the bench-level experiments verified the high feasibility of commercialization, pilot plant experiments were conducted outdoors. Although the experiments were continued for more than one year, only the results of the experiments conducted in winter when the waste water temperature was low are described here. The aeration tank residence time was established to simulate the operating pattern of a commercial plant.

2.6.1 Experimental method

(1) Experimental apparatus

The flow sheet of the pilot plant is shown in **Fig. 12**.

Aeration tank : 1 m × 1 m × 2 m high

Settling tank : 1.2 m ϕ × 1.6 m high

(2) Quality of waste water

The average quality of the waste water is given in **Table 4**.

(3) Acclimatization of sulfur-oxidizing bacteria

Initial sludge: Sewage treatment activated sludge

(4) Operating conditions

Aeration tank residence time : 3 to 30 h

Aeration tank ORP : +100 mV

Aeration tank pH : 6 to 7

Sludge return ratio : About 25% of waste water flow rate

Waste water temperature : 3 to 15°C

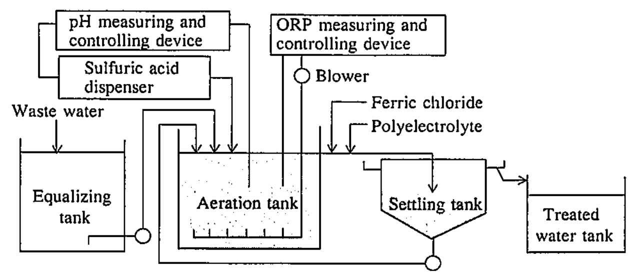

Fig. 12 Pilot plant flow sheet

Table 4 Average quality of waste water in pilot plant experiments

pH	12.4	$S_2O_3^{2-}$	197
COD	158	S^{2-}	29

Units in mg/L except for pH

(5) Addition of nutrient salts

Ammonium sulfate : 5 mg-N/L

Phosphoric acid : 1 mg-P/L

(6) Addition of coagulants

Ferric chloride : 5 mg/L

Polyelectrolyte : 0.5 mg/L

2.6.2 Summary of experimental results and discussion

(1) Quality of treated water

• $S_2O_3^{2-}$ and S^{2-} were certainly oxidized with the aeration time of 3 h. This means that the proposed waste water treatment system is adaptable to the variations in waste water concentrations.

• During the low-temperature winter period, the COD was stabilized at 20 mg/L or less, and the sulfur-oxidizing bacteria were fully resistant to the low-temperatures.

• The SS varied more than the COD. It is necessary to stabilize the SS, and optimize coagulation.

(2) Effect of change in aeration time

• Immediately after changing the aeration time, the treated water's SS slightly increased, but this had little or no effect on sulfur compound oxidation. Slight variations in the waste water flow rate through a commercial plant were thus considered not to be a problem.

• When the pilot plant was started up again after its shutdown, the COD of the treated water did not greatly change. This means that a commercial plant can be operated on stop-start basis.

(3) Multiplication of sulfur-oxidizing bacteria

• The MLSS and MLVSS increased when the aeration time was 3 h and decreased when the aeration time was 30 h. The decrease in the MLSS and MLVSS indicates that the rate at which the sulfur-oxidizing bacteria are lost by outflow to the treated water and endogenous respiration is greater than the rate at which they multiply. If the residence time is set at more than 30 h with the waste water concentrations of **Table 4**, the sulfur compounds flowing into the aeration tank will become insufficient for the long, continuous operation of the plant.

• The MLSS and MLVSS continued to decrease while the plant was shut down, but the rate of the decrease was relatively low. This is probably because during the shutdown of the plant, there was no flow of the MLSS into the treated water and the aeration rate was held at a very low rate, resulting in a lower endogenous respiration rate of the sulfur-oxidizing bacteria.

(4) Overall evaluation

• The oxidation of sulfur compounds by the proposed system is stable and commercially feasible.

• If the volume of incoming waste water sharply decreases, it is more economical to operate the plant on stop-start basis rather than to continuously operate the plant to treat the waste water at a reduced rate. Since the SS of the treated water (outflow of the sulfur-oxidizing bacteria) increases immediately after the start of the treatment, the treated water should be able to be returned to the plant.

• The sulfur-oxidizing bacteria multiplication rate is so low that surplus sludge is generated only in a small volume. The plant can be operated under such conditions as to generate little or no surplus sludge.

• The cost comparison of plants for treating waste water at a rate of 720 m^3/d is shown in **Table 5**. The equipment cost is converted to an annual cost by a specified formula and is added to the operating cost to arrive at the total cost.

2.7 Commercialization

2.7.1 Study of scale-up

When applying pilot plant data to commercial plant design, it is necessary to perform a reliable scale-up. When multiplying large amounts of bacteria such as sulfur-oxidizing bacteria in a large-capacity aeration tank and maintaining their activity at a high level, an environment suited for their growth must be achieved. The following two points were studied mainly with respect to the scale-up of the plant to treat the high-pH and sulfur compound-contaminated waste water:

(1) Introduction of two-stage pH control process

The pH of incoming waste water greatly varied. If the waste water was directly sent to the aeration tank, the pH of the waste water in the aeration tank was likely to exceed the target control range. A pH conditioning tank was installed ahead of the aeration tank to precondition and stabilize the incoming waste water's pH. This stabilized the pH the influent waste water going in to the aeration tank and made it possible to stably control the waste water's pH in the aeration tank at an optimum point over a narrow range.

(2) Introduction of submerged mixing-type diffuser

When improper mixing occurred in the corners and other parts of the aeration tank, the pH was likely to move out of the control range, reducing the activity of the sulfur-oxidizing bacteria. Compared with a conventional activated sludge treatment plant, more complete mixing in the aeration tank was considered necessary. In addition to a normal diffuser, a submerged mixing-type diffuser was installed in the bottom of the aeration tank to ensure uniform mixing.

2.7.2 Description of commercial plant

A commercial plant with a capacity of 720 m^3/d was constructed based on the scale-up study results. The flow chart of the plant is shown in **Fig. 13**. The treatment functions of the plant are as described below.

(1) The waste water is received in the equalizing basin to reduce the quantity and quality variations and is fed by the raw water pump to the preliminary pH conditioning tank. This pump can adjust the water flow rate, based on the COD of the raw water measured with an automatic analyzer, so that the COD loading can be held constant.

(2) After adjusting waste water pH in the preliminary pH conditioning tank, it flows under gravity into the aeration tank.

(3) In the aeration tank, the sulfur-oxidizing bacteria are agi-

Table 5 Treatment cost comparison of high-pH and sulfur compound-bearing waste water

Item/process	Oxidization by sulfur-oxidizing bacteria	Oxidation by ozone
Equipment cost	1	1.9
Operating cost	1	15.6
Total treatment cost	1	4.3

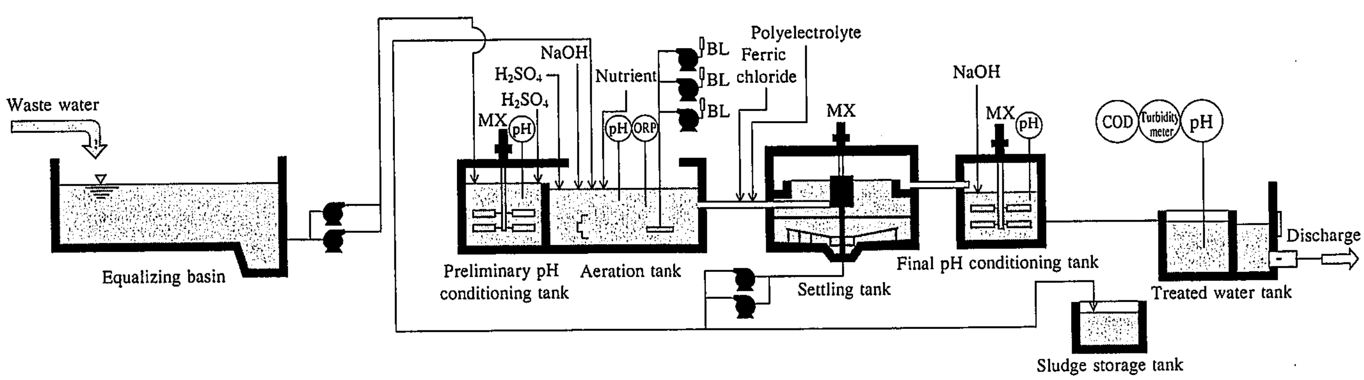

Fig. 13 Flow sheet of commercial plant

tated and mixed with the waste water by aeration. They aerobically react with the waste water, and oxidize the sulfur oxides in the waste water. The aeration tank has the functions of adding a pH conditioner to keep the pH constant in the aeration tank, controlling the aeration rate according to the ORP, and adding nutrients.

(4) The waste water after aeration flows under gravity to the settling tank. The iron salt and polyelectrolyte are added to the waste water as it flows to the settling tank.

(5) In the settling tank, the sludge containing the sulfur-oxidizing bacteria is separated from the supernatant liquid, and the settled sludge is returned to the aeration tank.

(6) The supernatant liquid from the settling tank is adjusted depending on its pH in the final pH conditioning tank and discharged as treated water through the treated water tank.

(7) When the sludge has multiplied in excess of the MLSS control concentration in the aeration tank, it is withdrawn as surplus sludge into the sludge storage tank.

3. Conclusions

This paper has described, centering on experimental data, that high-pH and sulfur compound-containing waste water can be biologically treated stably and at low cost. The initial target has been already achieved now that a commercial plant is operating smoothly. The developed process is considered to be applicable for treating other types of sulfur compound-contaminated waste water. For the time being, the technology will be improved for treating solid waste landfill leachate and the like. Sulfur-oxidizing bacteria are regarded as capable of also oxidizing solid sulfur and organic sulfur compounds contained in coal and other materials. Biological treatment has an extremely wide scope of application and is expected to make further technical progress. The authors will continue their efforts to establish biological treatment technology that is economical and friendly to the global environment.

References

1) Imai, K.: Autotrophic Bacteria. First edition, Kyoto, Kagaku Dojin, 1984, p. 63-76
2) Starley, J.T.: Bergey's, Manual of Systematic Bacteriology. Vol. 3. Williams & Wilkins, 1989, p. 1843
3) Miki, O., Kamori, H., Inoue, N., Fujii, M.: Journal of Japan Society on Water Environment. 18 (3), 231 (1995)
4) Miki, O., Kamori, H., Yabe, H., Fujii, M.: Journal of Japan Society on Water Environment. 19 (1), 40 (1996)
5) Koizumi, J.: Water and Waste. 31 (4), 26 (1989)