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Biological Deodorizing Technology

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Abstract:

Odor removal methods may be roughly divided into biological deodorization, adsorption, and chemical washing. Each method has advantages and disadvantages. The optimum method will suit the specific deodorizing and equipment conditions. Under general deodorizing conditions, a biological deodorizing process is often superior in terms of total cost. This paper outlines biological deodorizing technology, describes the research and development of a packed tower-type biological deodorizing method using Biocarrier, and presents a commercial application.

1. Introduction

Odor removal methods may be mainly classified into biological deodorization, adsorption, chemical washing, ozone oxidation, and combustion. Each method has advantages and disadvantages. The optimum method will suit the specific deodorizing conditions, such as concentration of the substance whose odor is to be removed and odor removal ratio, and equipment conditions, such as available space and availability of water treatment facilities.

Under general deodorizing conditions, the biological deodorizing method is often advantageous in terms of total cost (equipment cost plus operating cost). Where advanced treatment is required, biological deodorization can maintain its economic advantage in combination with activated carbon adsorption. This paper outlines biological deodorization technology, describes the research and development of a packed tower-type biological deodorizing method using Biocarrier, and presents a practical application.

2. Outline of Biological Deodorizing Technology

2.1 Mechanism and features of biological deodorization

The decomposition mechanism of malodorous substances by bacteria is illustrated in **Fig. 1**. The reactions involved may be explained as follows:

- Odorous components in gas are dissolved in water.
- The dissolved odorous components are adsorbed and absorbed by bacteria.
- The absorbed odorous components are oxidized and decomposed by the bacteria. (The bacteria acquire energy by oxidizing the odorous components.)

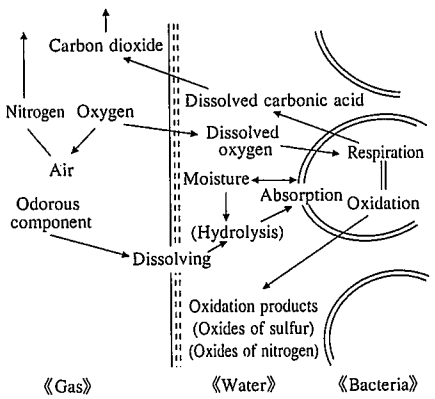

Fig. 1 Mechanism of decomposition of malodorous substances by bacteria[1]

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Given the above reactions, biological deodorization has the following features in principle:

- Water-soluble odorous components can be efficiently removed.
- Continuous removal of odorous components that are oxidizable and decomposable by bacteria.

2.2 Biological deodorizing system

To capitalize on biological deodorization's features, it is necessary to grow bacteria suited for odorous components to a high density, and to satisfy the following conditions:

(1) Maintain effective contact between odorous components and water (bacteria)

(2) Provide a supply of water, nutrients, and oxygen required for bacteria to maintain their activity

(3) Eliminate the adverse effects of oxidation products.

A packed tower-type biological deodorization system as shown in **Fig. 2** is available as a means to satisfy these conditions.

The system can achieve condition (1) by selecting an appropriate biological carrier. The biological carrier will be explained in detail in the next section. Condition (2) can be met by installing a sprinkling tank, spraying water onto the biological carrier, adding nutrients to the water as required, and aerating the water in the tank. Since the oxidation products and the like are dissolved in the sprinkling water, condition (3) can be satisfied by blowing down on the water in the tank and adjusting its pH.

2.3 Biological carrier

The biological carrier is an extremely important element that governs the performance of biological deodorization. Various biological carriers have been developed. Used in soil deodorization, andosol is a carrier in the broad sense of the term. The carriers listed in **Table 1** are commercially used in packed tower-type biological deodorization.

The biological carrier used by the authors is a saddle-type porous ceramic called Biocarrier. Biocarrier is a sewage treatment biological carrier developed jointly by Nippon Steel and the Ministry of Construction's Public Works Research Institute as part of the "Biofocus WT" project. It satisfies the following conditions required of a biological carrier for deodorization:

- Efficient contact between odorous component gas and carrier: Saddle shape
- Low pressure drop: Large free space ratio
- High bacterial loading: High porosity, large free space ratio and high specific surface area
- Water retention: High porosity, large free space ratio and high specific surface area
- High bacterial adhesion: Carrier composition and fine surface irregularities
- Continuity of performance: High-strength and non-deteriorating ceramic

The first Biocarrier developed was the type SI mainly composed of water-granulated blast-furnace slag. The composition of water-granulated blast-furnace slag is given in **Table 2**. The physical properties, general appearance, and manufacturing process flow sheet of Biocarrier SI are shown in **Table 3**, **Photo 1**, and **Fig. 3**, respectively. Biocarrier SI has the following features:

- Water-granulated blast-furnace slag, the main raw material is inexpensive.
- Since it contains calcium, the sintering temperature during manufacture is lower than is the case with alumina ceramics. Accordingly production costs are reduced.
- Since Biocarrier SI is a calcium-based carrier, it improves adhesion to the bacteria.

Biocarrier SI is inferior in acid resistance and cannot be used

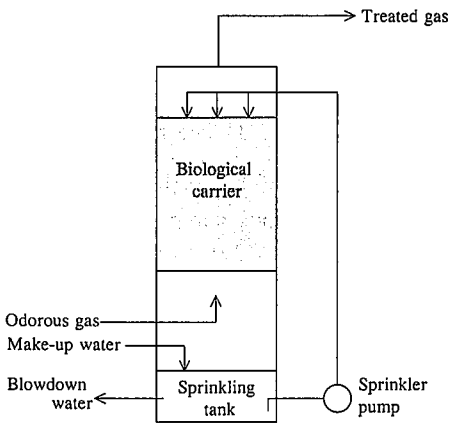

Fig. 2 Packed tower-type biological deodorization system

Table 2 Composition of water-granulated blast-furnace slag

Composition	Range (wt%)
CaO	40-44
SiO_2	32-35
Al_2O_3	13-16
MgO	4-8
Fe_2O_3	0.6-0.9

Table 3 Physical properties of Type SI saddle

Item / Size	Specific surface area (m^2/m^3)	Free space ratio (%)	Unit weight (kg/m^3)
3/4inch	335	77	540
1 inch	256	77	540

Table 1 Carriers commercially used for biological deodorization[2]

Carrier	Peat (natural organic fiber)	Combination carrier and adsorbent (activated carbon + zeolite)	Porous ceramic	Rice hull (fermented)	PVA particle (with activated carbon)	Fibrous sponge (urethane)
Odor source	Sludge thickening tank and elutriation tank	Contaminated water inlet culvert	Sludge thickening tank Sludge storage tank	Sludge thickening tank and equalizing tank	Dehydrated cake storage tower	Primary sedimentation basin Aeration tank
Design conditions						
Linear velocity (m/s)	0.062	0.1	0.1	0.12	0.2	0.3
Space velocity (h^{-1})	75	225	116	240	340	540
Pressure drop (mmAq)	130	100	10	84	30	30

Photo 1 Biocarrier

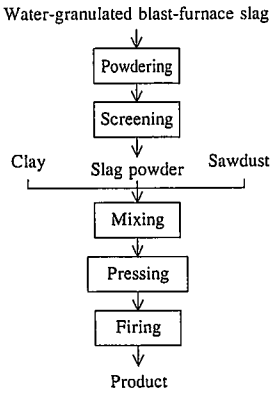

Fig. 3 Production flow sheet of Biocarrier SI

Table 4 Properties of Biocarrier

Type	SI	R	C
Main material	Granulated slag	Agalmatolite	Lignite char
Water content	37%	37%	50%
Crush strength	> 4 kg/piece	> 4 kg/piece	> 30 kg/piece
Acid resistance*	30%	0.2%	Trace

*Rate of weight loss after 24h of immersion in 5% sulfuric acid

in an acidic atmosphere. Two new types of Biocarrier were developed to allow the correct choice for specific deodorization conditions. Their properties are shown in **Table 4**. Type R is acid resistant, while Type C has acid resistance, high strength, and adsorptive capacity by itself.

3. Research and Development of Packed Tower-Type Biological Deodorization Technology

Extensive research and development work has been undertaken in this area. Introduced here are the experiments in which low pressure drop, one characteristic of Biocarrier, was confirmed; and the study of removal of hydrogen sulfide as one measure for increasing the space velocity.

3.1 Experiment to confirm low pressure drop of Biocarrier

3.1.1 Experimental method

(1) Experimental apparatus

The experimental apparatus was the same as shown in **Fig. 2**, except that water was not circulated but was discharged once used.

Packed bed capacity : 14.1 L
Packed bed size : 100 mm ϕ × 1,800 mm high
Carrier : Type R, 1/2, 3/4 and 1 in.

(2) Experimental conditions

Gas : Air (23 to 25°C)
Space velocity (SV) : 100 to 900 h^{-1}
Linear velocity (LV) : 0.05 to 0.45 m/s
Liquid-gas ratio (L/G) : 0 to 30 L/m^3
Bacteria (sludge) : 1 g per L of carrier

(3) Pressure drop measurement

The pressure drop was measured across 1,200 mm in the middle section of the packed bed to avoid the effect of turbulence at the air inlet and outlet.

3.1.2 Experimental results

The pressure drop per 1 m of Biocarrier packing height is shown in **Figs. 4** to **6**.

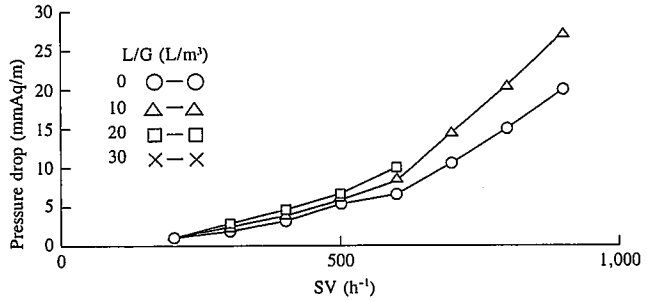

Fig. 4 Pressure drop through Biocarrier (1/2 in.)

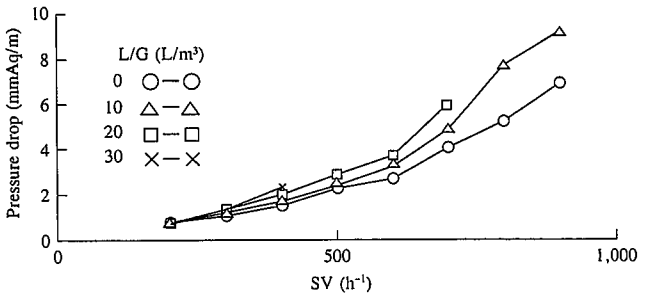

Fig. 5 Pressure drop through Biocarrier (3/4 in.)

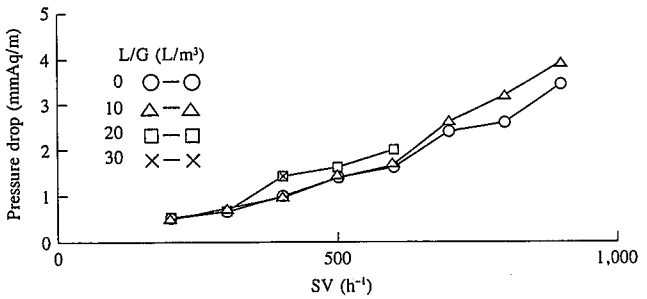

Fig. 6 Pressure drop through Biocarrier (1 in.)

3.1.3 Summary of experimental results and discussion

• The pressure drop at the space velocity of 100 h^{-1} was 1 mmAq/m or less, regardless of the carrier size.

• The pressure drop was small on the whole and considered to be the lowest level among biological carriers for packed towers.

• When the space velocity was increased at a high liquid-gas ratio, flooding occurred, making it impossible to measure the pressure drop.

• This experiment measured the pressure drop under general bacteria buildup. The pressure drop through biological carriers greatly varies with the amount and activity of bacteria. This fact must be fully taken into account when designing packed towers.

3.2 Study of hydrogen sulfide removal

3.2.1 Experimental method

(1) Experimental apparatus

The experimental apparatus is shown in **Fig. 7**.

Packed bed capacity in deodorizing tower : About 3 L
Packed bed size : 145 mm ϕ × 60 mm high × 3 stages
Biocarrier type and size : R and 3/8 in.
Linear velocity LV (m/s) = Space velocity SV (h^{-1})/20,000
Sprinkling tank : 1 L

(2) Methods for immobilizing and cultivating bacteria

Activated sludge was taken from an aeration tank at a sewage works and added into the sprinkling tank, so that the mixed liquor suspended solids (MLSS) became 1 g per L of carrier packing volume. For about one day, a sprinkler pump sprayed water onto the carrier to immobilize the bacteria. To cultivate the bacteria, gas was pumped into the water at a space velocity of 200 h^{-1}.

(3) Experimental conditions

Carrier gas	: Air (about 20°C)
Odorous gas	: Hydrogen sulfide (target concentration of 10 ppm)
Space velocity (SV)	: 200 to 2,400 h^{-1}
pH in spray water tank	: Controlled to 4.5, 5.5, and 6.5
pH adjustment method	: Automatic addition of sodium hydroxide according to pH meter readings
Sprinkling method	: Sprinkler was turned on and off at 15-minute intervals
Sprinkling rate	: 1.2 $m^3/m^2 \cdot h$
Make-up water	: Industrial water

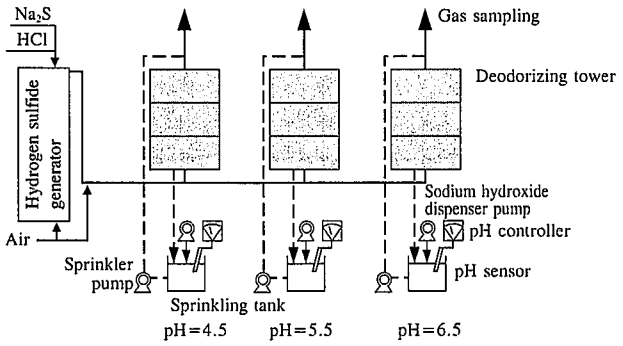

Fig. 7 Experimental apparatus for hydrogen sulfide removal

(4) Method for setting space velocity

When it was confirmed that the hydrogen sulfide concentration at the outlet of the deodorizing tower was stabilized under the detection limit of 0.1 ppm, the gas supply was increased, and the space velocity was raised by increments of 200 h^{-1}.

(5) Addition of nutrient salts

Nutrient salts were not initially included, but nitrogen and phosphorus were added later when the treatment became irregular.

(6) Blowdown of sprinkling tank

The sprinkling tank was initially blown down, but in the middle of the experiment the total replacement method was employed instead.

3.2.2 Experimental results

Hydrogen sulfide removal during start-up is shown in **Fig. 8**, hydrogen sulfide removal at the maximum space velocity in the deodorizing tower when the pH of the water was 6.5 is shown in **Fig. 9**, and the pressure drop through the deodorizing tower is shown in **Fig. 10**.

• Deodorization was most stable when the pH of the sprinkler water was 6.5. The outlet hydrogen sulfide concentration was 0.1

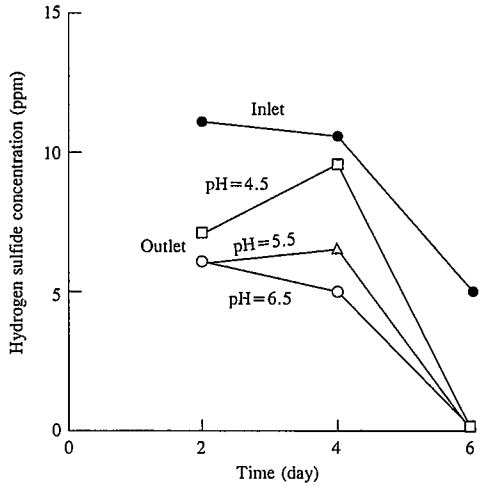

Fig. 8 Treatment during start-up

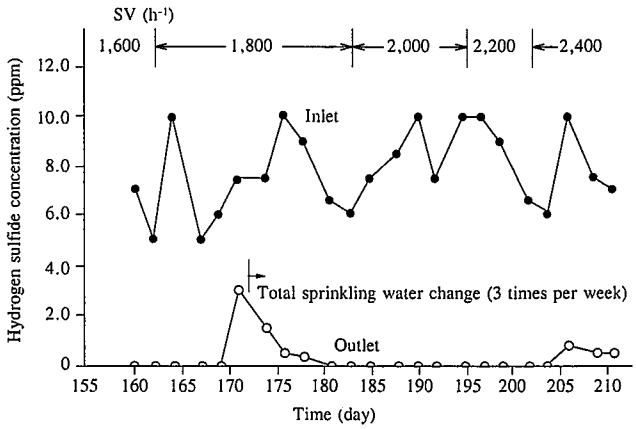

Fig. 9 Results of hydrogen sulfide removal experiment (sprinkling water pH = 6.5)

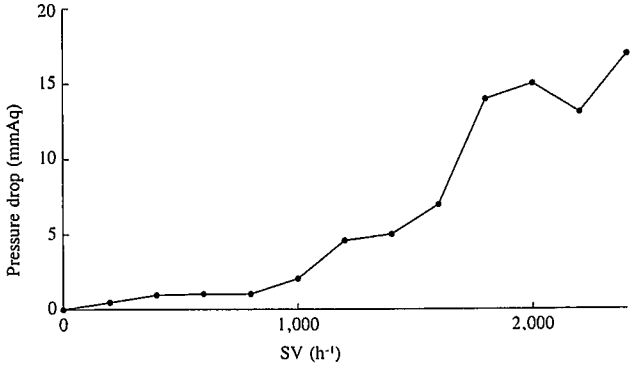

Fig. 10 Pressure drop during hydrogen sulfide treatment

ppm or less when the space velocity was up to 200 h^{-1}.

• About 1 month after the start-up, the hydrogen sulfide removal capability continued to decline despite the pH control of the sprinkler water. When the water in the sprinkling tank was analyzed, the nitrogen and phosphorus concentrations were each 1 mg/L or less. Judging that nitrogen and phosphorus were insufficient to maintain the activity and growth of bacteria, a nutrient (ammonium phosphate) was added into the sprinkling tank. When the nutrient was added so that the nitrogen and phosphorus concentrations in the sprinkling tank would exceed 20 mg/L each immediately after the addition, the bacteria recovered their hydrogen sulfide removal capability by the next day. When the nutrient salt was added three times per week under the same conditions, treatment failures due to the nutrient salt deficiencies ceased.

• Treatment failures occurred at space velocities of 1,400 to 1,800 h^{-1} in decreasing order of sprinkler water controlled pH. Such treatment failures disappeared when the sprinkler water was replaced three times per week at higher space velocities.

• When the sulfate ion concentration in the sprinkler water was measured to find the sulfur balance, it was confirmed that the absorbed hydrogen sulfide was almost completely oxidized into sulfuric acid. The consumption of sodium hydroxide used for pH control was approximately twice the molar quantity of the hydrogen sulfide removed.

3.2.3 Discussion

• Since the deodorizing tower inlet hydrogen sulfide concentration greatly varied during start-up, the outlet hydrogen sulfide concentration also varied. On the sixth day, the outlet hydrogen sulfide concentration dropped below 0.1 ppm. This suggests that the bacteria were already cultivated at that point.

• Nutrient salt deficiencies are certain to reduce the bacteria's hydrogen sulfide removal capability. Chemicals need not be always added as nutrient salts, but sewage work effluent may be used as an alternative nutrient salt.

• As the sprinkler water is circulated, so do biological activity inhibitors increase. It is difficult to identify such inhibitors by this experimental work alone. Judging from the experimental conditions, the rise in the concentration of sulfate ion or sodium sulfate is considered responsible for biological activity inhibition.

• Judging from the stability of hydrogen sulfide removal when the pH of the sprinkler water is high, there is a strong possibility that hydrogen sulfide removal is controlled by its absorption into water.

• If the sprinkler water pH, nutrient salt, sprinkler water blowdown, and other conditions are properly controlled, the hydrogen sulfide concentration can be reduced from 10 ppm to 0.1 ppm at the space velocity of 200 h^{-1}.

• Judging from the oxidation of hydrogen sulfide into sulfuric acid, predominant bacteria in the deodorizing tower are sulfur-oxidizing bacteria.

• In a chemical deodorization process that absorbs hydrogen sulfide with a sodium hydroxide solution, for example, the chemical oxygen demand (COD) of the absorbing solution becomes so high that oxidation treatment of it may become necessary. The proposed process oxidizes hydrogen sulfide within the system, so that there seems to be no need for the oxidation treatment of blowdown water.

• The variability of deodorizing tower pressure drop rose with increasing space velocity, probably due to bacteria multiplication and sloughing off.

• This experimental work used air (with an approximate oxygen concentration of 21%) as the carrier gas. The effects of lower carrier gas oxygen concentrations must also be taken into account.

4. Commercialization of Biological Deodorization Process[3)]

The commercial biological deodorization plants constructed at Nippon Steel are listed in **Table 5**. The equipment outline and operating data of the No. 2 biological deodorization plant are introduced below.

4.1 Plant description

The No. 2 biological deodorization plant was built to remove the odor of waste gas from an activated sludge aeration tank and other units used to treat contaminated water and waste water. Since particularly severe odor removal requirements were imposed in view of local environmental conditions, an activated carbon adsorption tower was provided after the biological deodorizing tower. The flow sheet of the biological deodorization plant is given in **Fig. 11**, its main specifications are listed in **Table 6**, and its general view is shown in **Photo 2**.

The odorous components to be removed are oxidized into acid substances in the deodorizing tower and sprinkling tank. If left in this condition, the acid substances turn the entire system acidic lowering the odor removal rate. To keep the pH at about 7 (neutral) as appropriate for biological treatment, equipment is installed to neutralize the sprinkler water with sodium hydroxide. The biological deodorization plant is fully automatic and usually left unattended.

Table 5 Commercial biological deodorization plants

Odor source	Odorous air flow rate (m^3/min)	Activated carbon adsorption tower
1 Sludge treatment at sewage treatment plant	44×2 lines	Yes
2 Foul water and waste water treatment plant	70×1 line	Yes
3 Sludge treatment at sewage treatment plant	75×1 line	Yes
4 Sand basin at pump station	70×2 lines	Yes
5 Trickling filter	550×1 line	No
6 Contaminated water and storm water sand basin at pump station	93×1 line	No
7 Contaminated water and storm water sand basin at pump station	90×1 line	No
8 Sand basin at sewage treatment plant	150×2 lines	Yes
9 Sewage sludge dryer	350×2 lines	Yes

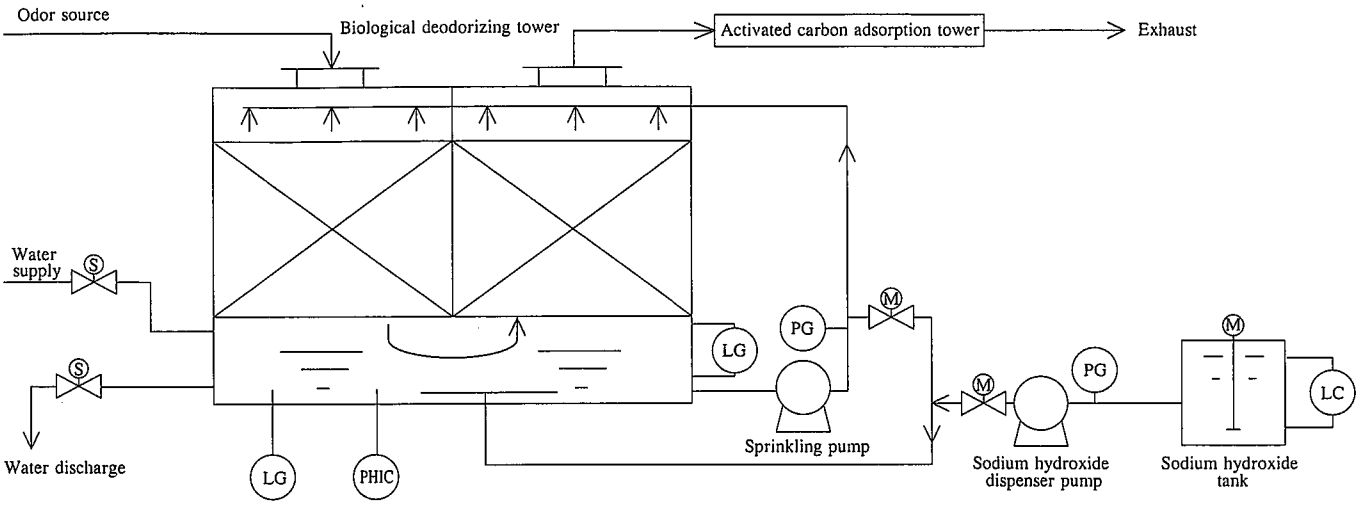

Fig. 11 Flow sheet of biological deodorization plant

Table 6 Main specifications of biological deodorization plant

Item	Main specification
Capacity	70m³/min
Biological deodorizing tower	Made of FRP, rectangular, 5,130 mm × 2,560 mm × 3,000 mm high
Packing	Biocarrier SI, 3/4 in. Volume: 21 m³

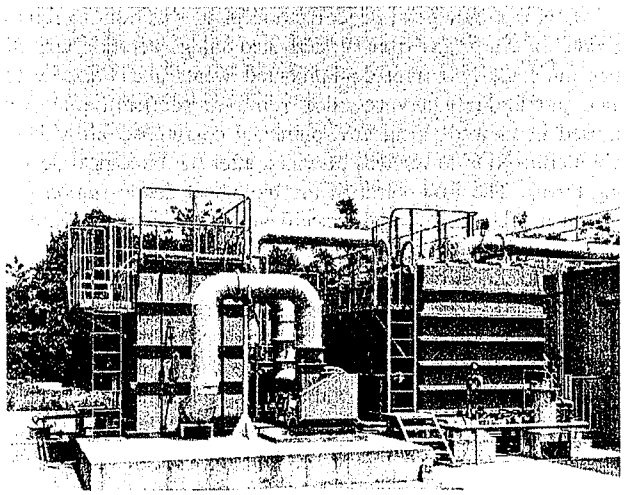

Photo 2 General view of biological deodorization plant

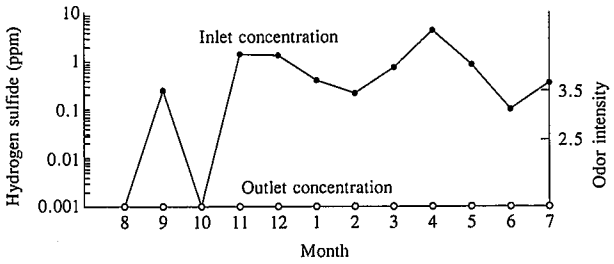

Fig. 12 Change in hydrogen sulfide removal for one year

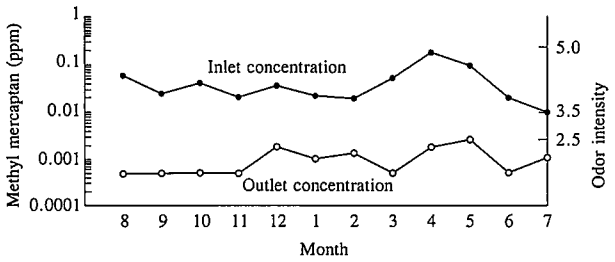

Fig. 13 Change in methyl mercaptan removal for one year

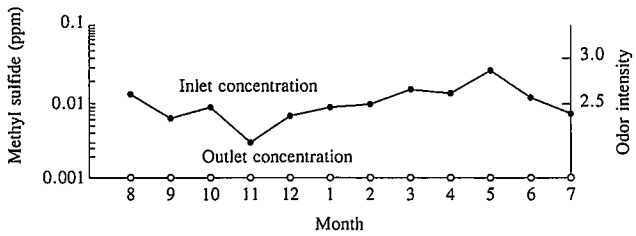

Fig. 14 Change in methyl sulfide removal for one year

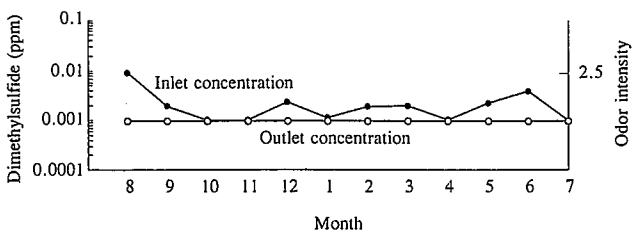

Fig. 15 Change in dimethylsulfide removal for one year

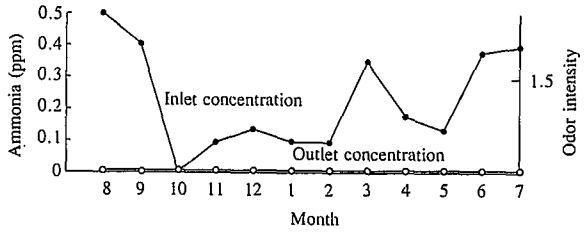

Fig. 16 Change in ammonia removal for one year

Table 7 Comparison of plant installation area and operating costs

Deodorization method	Biological deodorization	Soil deodorization	Activated carbon adsorption	Chemical washing
Installation area	1	18	0.8	1
Operating cost	1	2.8	8	7

4.2 Operating performance

The biological deodorization plant has been operating smoothly. As shown in **Figs. 12** to **16**, the deodorizing tower outlet concentrations of major odorous components — hydrogen sulfide, methyl mercaptan, methyl sulfide, dimethylsulfide and ammonia — are very stable.

- The main odorous components all had odor intensities of 2.5 or less at the deodorizing tower outlet. This means that the biological deodorizing tower alone can meet the odor intensities of 2.5 to 3.5 stipulated in the Offensive Odor Control Law.
- When measured by a sensory test method at the space velocity of 200 h^{-1}, the outlet odor concentration was 31 against the inlet odor concentration of 23,000.
- **Table 7** shows the comparison between the biological deodorization process and other deodorization processes in terms of plant installation area and operating costs based on equivalent deodorizing conditions.

5. Conclusions

The packed tower-type biological deodorizing process has many features as discussed in this paper. Thanks to its low total cost, usage has been spreading rapidly in recent years. As complaints about odor are still increasing in the community, needs for deodorization will mount further, and higher deodorization rates will be demanded. Irrespective of the deodorization rate required, the total cost will be still reduced if the biological deodorizing process is adopted as a preliminary treatment method. The authors will continue their work to improve the capacity and efficiency of biological deodorization and to tackle the development and commercialization of deodorization processes of higher cost performance by optimally combining the biological deodorization method with other deodorization methods.

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