0273-2289/92/32(1/3)—0135$02.80

Biological Deodorization of Dimethyl Sulfide Using Different Fabrics as the Carriers of Microorganisms

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Received June 1, 1991; Accepted November 7, 1991

ABSTRACT

Biological deodorization of dimethyl sulfide (DMS) was studied using nine unwoven fabrics as the carriers of microorganisms in a laboratory-scale deodorizing system. The activated carbon fabric FN-200CF-15 was the best packing material compared with other packing materials used, on the basis of removal rate. The maximum removal rate (V_m), evaluated by using Michaelis-Menten equation, was 2.28 g-S·kg-dry fab.$^{-1}$·day^{-1} in this fabric biofilter. The critical load of DMS in this fabric biofilter was dependent on space velocity (SV), determined as 0.78 and 0.66 g-S·kg-dry fab.$^{-1}$ at SV 100 and 150 h^{-1}, respectively.

Strain IM1 isolated from the carbon fabric FN-200CF-15 biofilter in modified Waksman (MW) medium successfully degraded DMS as well as hydrogen sulfide (H_2S), methanethiol (MT), and dimethyl disulfide (DMDS) in batch test. The DMS removal rates (g-S·cell^{-1}·h^{-1}) by this strain measured in batch culture and calculated in FN-200CF-15 biofilter by the cell numbers appeared in MW medium were found almost equal, indicating that strain IM1 may be the dominant microorganism in this biofilter.

Index Entries: Dimethyl sulfide (DMS); activated carbon fabric; biofilter; biological deodorization.

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INTRODUCTION

Sulfur gases such as hydrogen sulfide (H_2S), methanethiol (MT), dimethyl sulfide (DMS), and dimethyl disulfide (DMDS) are of strong, malodorous nature. They exceed odor threshold even at low concentrations, and therefore, they are highly objectionable from an environmental point of view. The major release of these gases into the natural environment is from pulp and paper mills, natural gas and oil refinery industries, wastewater treatment plants, sewerage systems, compost plants, steel industries, and so on. Recently, to remove these compounds, biological methods using microbial activities for degradation of these compounds have attracted great attention. These methods are more efficient and economical than physicochemical ones if the proper operation is carried out. We have demonstrated the effectiveness of a fibrous peat as a carrier of microorganisms to remove various sulfur gases (*1–3*). However, among sulfur gases, DMS was the most difficult to degrade biologically (*2–4*). We also found that unwoven fabrics as a carrier showed higher removability of MT compared with fibrous peat (*5,6*).

In this respect, biological deodorization of DMS was investigated using various unwoven fabrics as the carriers of microorganisms and isolation of DMS-degrading bacteria was tried from the materials.

MATERIALS AND METHODS

Fibrous Packing Materials

Nine types of activated carbon fabrics and other fibrous packing materials were used as the carriers of microorganisms for DMS degradation. All of these materials were processed as a type of unwoven cloth. They are:

1. Rayon, polyester, acryl (Japan Vilene Co., Ltd., Tokyo, Japan);
2. Asgard, (proprietary name of activated carbon fabric; Otsuka Ind., Co., Ltd., Shiga Pref., Japan);
3. FN-200CF-15, FN-300PP-15; FN-300PS-15, FH-150PE-15 (Osaka Gas Co., Ltd., Osaka, Japan);
4. FN-200AC (Japan Vilene Co., Ltd., Tokyo, Japan).

Packing materials (2–4) were the activated carbon type fabrics. The moisture content (percentage) of each fabric was determined by drying for more than 8 h at 80°C. The pH value of each fabric was determined in the suspension of dry fabric and distilled water (one part of dry fabric and 19 or 39 parts of distilled water). Table 1 shows some of the properties of these unwoven fabrics.

Table 1
Some Properties of the Unwoven Fibrous Packing Materials

Fabrics	Composition	Elemental analysis C	H	N	S	ash	pH	Moisture content, %	Specific surface area, $m^2 \cdot g^{-1}$
Rayon	Rayon	42.5	6.5	0	0	0	6.1[b]	8.78	242[d]
Polyester	Polyester	62.2	4.5	0	0	0.6	5.4[b]	0.91	33[d]
Acryl	Acrylic	67.9	5.9	26.9	0	0	5.2[b]	0.95	<3[d]
Asgard	Activated carbon fabric made from rayon	56.8	3.7	4.4	0.4	7.3	2.61[b]	8.52	504[d]
FN-200CF-15	Carbon fiber (20%) + fibrous charcoal (80%)[a]	91.4	0.5	0.6	0	0.4	5.53[c]	4.98	1200[e]
FN-150PE-15	Polyester (30%) + fibrous charcoal (70%)	86.0	3.9	0.3	0	0	5.36[c]	3.18	1050[e]
FN-300PS-15	Fibrous charcoal (100%)	89.2	0.8	0.4	0.1	0.2	5.28[c]	1.95	1500[e]
FN-300PP-15	Polypropylene (10%) + fibrous charcoal (90%)	70.4	1.2	0.2	0	0	4.84[c]	17.7	1350[e]
FN-200AC	Polyacrylonitrite	65.7	2.0	4.0	0.3	1.6	5.49[c]	21.8	562[d]

[a] Surface area of the fibrous charcoal is 1500 $m^2 \cdot g^{-1}$.
[b] 1:19 (fab.:water) ratio (*see* text).
[c] 1:39 (fab.:water) ratio (*see* text).
[d] The values were measured by the determination of pore volume distribution by methyl alcohol isotherm method (7).
[e] The values were calculated from fibrous charcoal content of the fabrics.

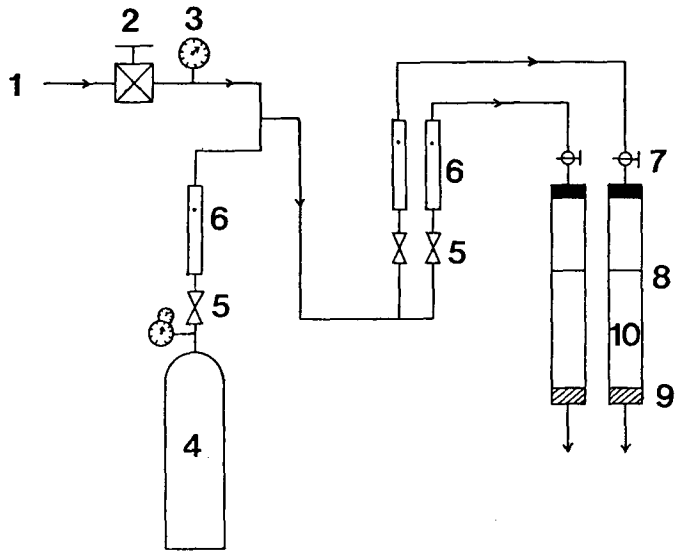

Fig. 1. Schematic diagram of the laboratory-scale fabric biofilter system. 1. Air; 2. Regulator; 3. Pressure gage; 4. Gas cylinder; 5. Control valve; 6. Flow meter; 7. Three way cock; 8. Glass column (biofilter); 9. Saran net; 10. Fabric.

Volatile Sulfur Gas

The DMS used in this experiment was supplied from a gas cylinder containing 2,000 ppm (inert gas N_2) (Takachiho Co., Inc., Tokyo, Japan). However, during the acclimation period, DMS solution (Kanto Chemical Co., Inc., Tokyo) was used for the production of the DMS gas as previously described (2). H_2S and MT were supplied from each gas cylinder (Takachiho Co., Inc., Tokyo, Japan), and DMDS was supplied from DMDS solution (Tokyo Chemical Co., Inc., Tokyo, Japan).

Acclimation and Removal Experiments

Figure 1 represents the schematic diagram of the laboratory-scale deodorizing system. The experimental conditions for acclimation are shown in Table 2, and all experiments were performed at room temperature ($20 \pm 2°C$).

A definite amount of chips (size: 10 mm × 10 mm) of fibrous packing materials were seeded by spraying or submerging with aerobically digested sludge of night soil as a seed of microorganisms in the similar way as previously mentioned (2), and the moisture content was kept more than 80%. In the case of Asgard, neutralization was done with 1.6 mol $Ca(OH)_2$/kg dry-fab. of before seeding night soil sludge because of its low pH. Thereafter, fabrics were packed into their respective glass columns (50 mm inner diameter × 400 mm height, often referred to as biofilters) and 5 ppm of the DMS gas evaporated from DMS solution by air

Table 2
Experimental Conditions for Acclimation

Packing materials	Parameters					
	Dry-wt, g	Packed height, mm	Packed volume, mL	Bulk density g/l	Space velocity, h^{-1}	Inlet concentration of DMS, ppm
Rayon	27.0	153	300	90	50	5-30
Polyester	24.8	153	300	83	50	5-30
Acryl	21.6	153	300	72	50	5-30
Asgard	28.0	153	300	93	50	5-80
FN-200CF-15	17.0	153	300	56.7	50	5-60
FN-200AC	21.5	153	300	71.7	50	5-60
FN-300PP-15	23.5	153	300	78.3	50	5-60
FN-300PS-15	17.2	153	300	57.3	50	5-30
FH-150PE-15	18.2	153	300	60.7	50	5-30

flow was supplied into each of these glass columns and the inlet and outlet gas concentrations were measured by gas chromatography regularly. When the outlet gas concentration was nearly zero, the inlet gas concentration was increased to a desired higher level. This process was repeated until a constant level of outlet gas concentration was detectable. At this stage, the process of acclimating microorganisms was assumed to be completed. During this period, a space velocity (SV, gas flow rate·(fabric packed volume)$^{-1}$, h^{-1}) was maintained at 50 h^{-1}.

After the gas supply was started, 50 mL of phosphate buffer solution (pH 7.0) was splashed into the columns manually every 2 d to adjust pH and to maintain sufficient moisture of the carriers. The drainage water from each biofilter was collected periodically for the analysis of sulfate ion concentration.

After the acclimation of microorganisms in each fabric biofilter was confirmed, the removal rate of DMS was measured nearly every 2 h by changing both the inlet concentration and space velocity. In this case, DMS gas was supplied directly from the gas cylinder after necessary dilution by air flow (Fig. 1). SV (h^{-1}) considered for DMS gas removal experiments were 50, 100, 150, and 200. An appropriate amount of phosphate buffer (normally 50 mL) was also sprayed into each biofilter at a certain time interval.

Bacterial Counting

Five grams (wet wt) of each fabric after each run of the experiment were homogenized in an appropriate amount (45 or 95 mL) of sterilized water in the respective homogenizing cups for 10 min at 10,000 rpm (EX-3,

Table 3
Compositions of Media Used for Bacterial Countings

Name of media	MW		DMSO		Nutrient-agar	
Compositions (g/1)	KH_2PO_4	3	K_2HPO_4	1.55	$Na_2HPO_4 \cdot 12H_2O$	2
	NH_4Cl	0.1	NaH_2PO_4	0.85	NaCl	3
	$MgSO_4 \cdot 7H_2O$	0.5	$(NH_4)_2 \cdot SO_4$	0.1	Yeast extract	3
	$CaCl_2 \cdot 2H_2O$	0.3	NH_4Cl	2	Meat extract	3
	$FeSO_4 \cdot 7H_2O$	0.01	$FeSO_4 \cdot 7H_2O$	0.01	Peptone	15
	$Na_2S_2O_3 \cdot 5H_2O$	8	Yeast extract	0.1	Agar	20
	Gellan gum	5	DMSO[a]	1		
			Gellan gum	5		

[a]U; mL/1.

Nihon Seiki Ltd., Tokyo). Suspended solutions with different dilution ratios were then spread onto the agar plates containing different media. After incubation for about 2 wk at 30°C, the number of colonies on the plates, in each case, were counted. The following media were used: (a) modified Waksman (MW); (b) dimethyl sulfoxide (DMSO); and (c) nutrient-agar (NA). Table 3 shows the compositions of each medium. The initial pH value of each medium was adjusted at 7.

Isolation of Dominant Microorganisms

Among the various fibrous packing materials examined, FN-200CF-15 fabric was found as the best carrier of microorganisms for DMS degradation on the basis of its removal efficiency. Therefore, enrichment culture and isolation of the dominant microorganisms that inhabited this fabric were carried out. As a microbial source for enrichment culture, the colonies appearing on three different agar plates (Table 3) were used. All the isolates from each solid medium with the same dilution ratios were transferred into the respective bubbling bottle containing 250 mL of inorganic medium containing ($g \cdot l^{-1}$) KH_2PO_4 2; K_2HPO_4 2; NH_4Cl 0.4; $MgCl_2 \cdot 6H_2O$ 0.2; $FeSO_4 \cdot 7H_2O$ 0.01. With the supply of DMS gas of 40–50 ppm at the flow rate of 200 mL/min, the bottles were incubated at room temperature, 27 ± 2°C. During the incubation time, inlet and outlet gas concentrations were measured by gas chromatography. When any fall in pH was noted, the pH of cultures was readjusted to around 7 with 2N NaOH. When the outlet concentration was found less than 5 ppm, a part of the culture was sampled and retransferred to the newly prepared inorganic medium with the inoculation ratio of 1:4 (50 mL of the culture in 200 mL of fresh inorganic medium) and subculturing was subsequently carried out by the same procedure as previously described. At each inoculation stage, culture and subculture samples were also spread onto the agar plates and the dominant microorganisms were purified. One loopful cell of each selected colony from solid medium was inoculated into 5 mL of the same liquid medium, and incubated at 30°C with reciprocal shaking (120 strokes/

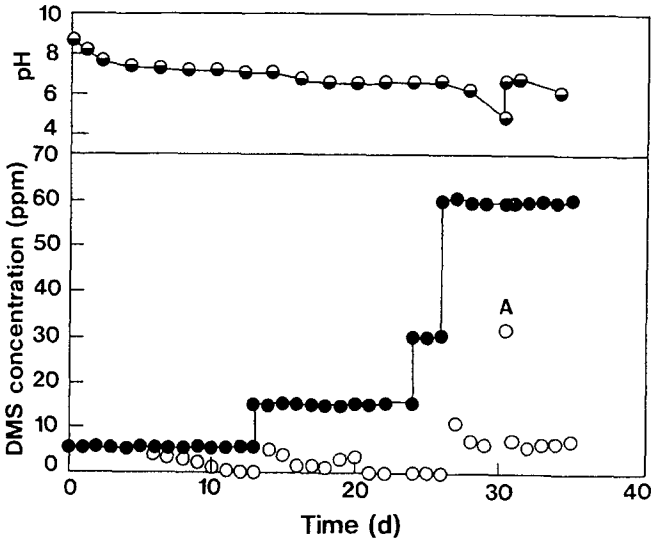

Fig. 2. Time course of acclimation in FN-200CF-15 biofilter. ● Inlet concentration of DMS; ○ Outlet concentration of DMS; ◒ pH.

min). After the growth was confirmed, the culture broth was transferred into the 500 mL shaken flask containing 95 mL of the inorganic medium. The flask was tightly sealed with a butyl rubber stopper, and DMS gas was injected into the flask to give a headspace gas concentration of around 80 ppm in the similar manners as previously described (*8*). During the incubation period at 30°C on the rotary shaker (120 rpm), the headspace gas was measured, and the specific uptake rate of DMS was determined by the same methods as previously described (*8*).

Similarly, the specific uptake rates of H_2S, MT, and DMDS by an isolate were also evaluated as previously mentioned.

Analysis

In all the experiments, gas concentrations were measured by gas chromatography (GC-4BM or GC-14A, Shimadzu Co., Ltd., Kyoto, Japan). Sulfate ion concentration was measured by ion chromatography (HIC-6A, Shimadzu). Details of the analytical procedures were followed by those previously reported (*2*).

RESULTS AND DISCUSSION

Acclimation of the Microorganisms

Figure 2 illustrates the time course of acclimation and pH change in FN-200CF-15 packed biofilter. Similar acclimation patterns were obtained for other activated carbon fabrics. By the analysis of sulfur ion of drainage

Table 4
Maximum Removal Rates
of DMS in Different Fabric Biofilters

Packing materials	Parameters	
	V_m[a]	K_s[b]
Rayon	0.50	3.67
Acryl	0.45	3.14
Polyester	0.83	1.83
Asgard	1.33	8.68
FN-200CF-15	2.28	6.28
FN-200AC	1.16	5.80
FN-300PP-15	1.08	6.27
FN-300PS-15	0.64	2.91
FH-150PE-15	0.66	3.24
Peat (2)	0.38	10.00
Polypropylene (6)	0.34	3.40
Nylon (6)	0.47	4.10

[a]U; g-S/kg-dry fab./d.
[b]U; ppm.

by ion chromatography, DMS was confirmed to be degraded to sulfate (data not shown). The acclimation period, when the outlet concentration of DMS became constant in the biofilter was found to be 25–35 d. During this period, a gradual fall in pH was observed (Fig. 2), which was sharp in the later stage of acclimation because of high accumulation of sulfate ion concentration (data not shown) and thus, the removal of DMS gas was highly inhibited as illustrated by Fig. 2A. However, after spraying the phosphate buffer (pH 7) sufficiently, fast recovery in DMS removal was observed as shown in Fig. 2. This means that the microorganisms responsible for DMS degradation in these biofilters are sensitive to low pH. In case of FN-200CF-15, FN-200AC, and FN-300PP-15 biofilters where maximum removal rates of DMS were relatively larger (see Table 4), pH decrease was observed larger than that in other fabric biofilters.

Kinetics of Gas Removal

The DMS removal was evaluated by the following kinetic analysis. Assuming the plug flow of the gas into the biofilters and applying the Michaelis-Menten equation, the following equation was obtained:

$$-dC/dl = V_m \cdot C/(K_s + C) \cdot (S_a/F) \cdot \alpha \quad (1)$$

$$= V_m \cdot C/(K_s + C) \cdot (1/L \cdot SV) \cdot \alpha \quad (2)$$

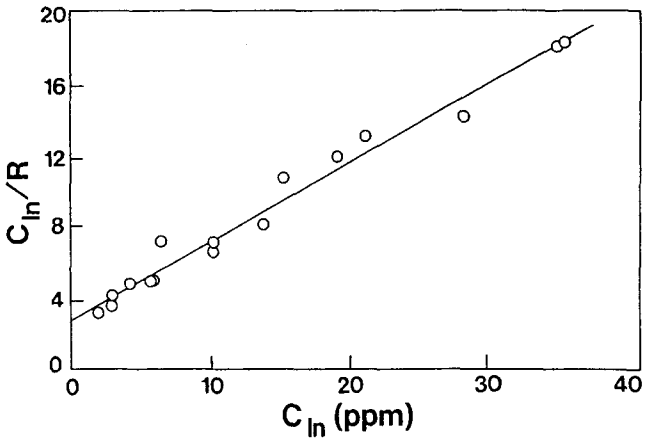

Fig. 3. Kinetic analysis of DMS in FN-200CF-15 biofilter (*see* text).

where *C:* concentration of DMS (ppm); *l:* length of column (m); V_m: maximum removal rate (g-S/kg-dry fabric/d); K_s: saturation constant (ppm); S_a: cross section of column (m^2); *F:* gas flow rate ($m^3 \cdot d^{-1}$); *L:* height of fabric packed(m); *SV:* space velocity (d^{-1})$=F \cdot (S_a \cdot L)^{-1}$; α: conversion coefficient (kg-dry fabric/g-S^{-1}). Converson coefficient α defined by Eq. (3) was used to convert the unit of concentration to ppm.

$$\alpha = (22.4 \times (273 + T)/273) \times 10^6 / (32.1 \times 1000) \cdot W / V \quad (3)$$

where *T:* temperature (°C); *V:* volume of fabric (m^3); *W:* dry wt of fabric (kg); 32.1: atomic weight of sulfur. Equation (4) was obtained by integrating Eq. (1) under the condition of $C = C_0$ at $1 = 0$, $C = C_e$ at $1 = L$,

$$\alpha / SV(C_0 - C_e) = K_s / V_m \cdot 1 / (C_0 - C_e) / \ln(C_0 / C_e) + 1 / V_m \quad (4)$$

Setting $R = SV(C_0 - C_e)/\alpha$ and $C_{ln} = (C_0 - C_e)/\ln(C_0/C_e)$, Eq. (4) is simplified as follows:

$$C_{ln} / R = C_{ln} / V_m + K_s / V_m \quad (5)$$

Wolf-plot of C_{ln}/R vs C_{ln} for FN-200CF-15 biofilter is represented in Fig 3. The maximum removal rate (V_m) and the saturation constant (K_s) obtained are presented in Table 4 together with those of other materials and previous results (*2,6*). Among the 12 different kinds of packing materials, the maximum removal rate, V_m is highest for FN-200CF-15 fabric, which is six times larger than that of peat and approximately twice that of Asgard and FN-200AC. In this respect, activated carbon fabric FN-200CF-15 is the best packing material as the carrier of the microorganisms for DMS degradation. Activated carbon fabrics like Asgard, FN-200AC, and FN-300PP-15 are also potential carriers for the degradation of DMS. The specific surface areas for activated carbon fabrics as shown in Table 1 are

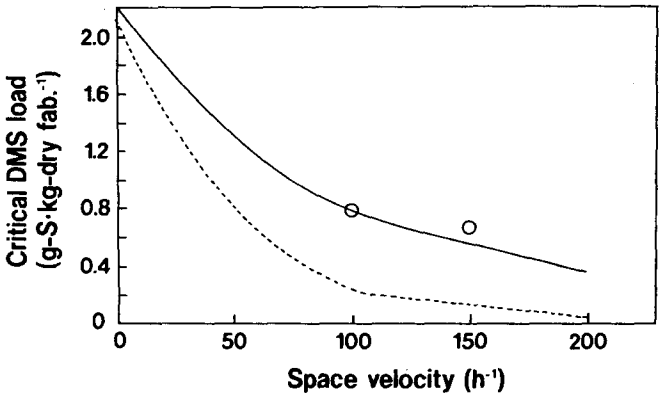

Fig. 4. Critical loads of DMS at various SV. Solid and dashed lines correspond to 0.2 and 0.02 ppm of DMS outlet concentrations, respectively.

calculated data based on the fraction of fibrous charcoal in these materials and thus, total surface area for the fabrics, FN-200CF-15, FN-300PP-15 will be almost the same as that for FN-300PS-15. It is obvious that the surface areas for these activated carbon fabrics are larger compared with the others (Table 1), suggesting that these activated carbon type fabrics have an advantageous feature for inhabiting microorganisms over other fabrics.

Determination of Critical Load

The permissible concentration of DMS in outlet was prescribed as 0.2–0.02 ppm by the Offensive Odor Control Law in Japan. In the FN-200CF-15 fabric biofilter, the critical loads of DMS to satisfy this outlet concentration were theoretically calculated at various SV as follows. Equation (5) can be converted as Eq. (6).

$$SV = \alpha / (C_o - C_e) \cdot V_m \cdot C_{ln} / (K_s + C_{ln}) \quad (6)$$

Let C_e be 0.2 or 0.02 in Eq. (6), and the change of SV accompanies the change of Co. By using of values of V_m and K_s shown in Table 4, the values of C_o can be estimated at various values of SV. The critical loads of DMS are calculated by Eq. (7) using the values of C_o obtained from Eq. (6).

$$\text{Load} = SV \cdot C_o / \alpha \quad (7)$$

Figure 4 shows the relationship between critical loads of DMS and SV. The practical values obtained by the experiment were also shown in Fig. 4; $C_o = 7.80$ ppm, $C_e = 0.02$ ppm at $SV = 150\ h^{-1}$, and $C_o = 13.75$ ppm, $C_e = 0.19$ ppm at $SV = 100\ h^{-1}$. It is obvious that the critical load of DMS becomes lower when SV becomes larger in the FN-200CF-15 fabric biofilter.

Bacterial Counting

Table 5 represents the results of the bacterial counting in different media, which was carried out at the termination of each experiment.

Table 5
Bacterial Counting in Different Media

Packing materials	Media (cfu/dry-fab.)		
	DMSO	MW	NA
Rayon	1.7×10^8	1.05×10^8	5.1×10^7
Acryl	4.1×10^8	3.52×10^8	4.1×10^8
Polyeseter	4.42×10^8	3.89×10^8	4.15×10^8
Asgard	3.25×10^8	2.84×10^8	2.27×10^8
FN-200CF-15	8.76×10^9	1.29×10^{10}	8.64×10^9
FN-200AC	2.64×10^9	2.87×10^9	N.D.[a]
FN-300PS-15	3.47×10^9	2.45×10^9	2.04×10^9
FH-150PE-15	2.99×10^9	2.11×10^9	1.32×10^9
FN-300PP-15	1.96×10^9	2.85×10^9	N.D.

[a]N.D., Not determined.

When the colony numbers were compared with the corresponding removal rates, the cell number in FN-200CF-15 was the largest in three media. Although there is no definite correlation between the surface area and the cell number detected among these carbon fabrics, it seems that the number of cells in carbon fabrics were relatively larger than other materials. The main reason why the FN-200CF-15 showed the maximum value both in V_m (Table 4) and in the cell number is not clear yet, but will be partly attributable to the physical and chemical properties of the fabric, which is a mixed material of carbon fiber and activated carbon fabric.

As will be described later, we have already isolated some DMS-degrading bacteria from the materials, and the isolated microorganisms are going to be inoculated onto the fabrics and the comparison of the removability will be carried out to verify the data obtained in this experiment.

Enrichment and Isolation of the Dominant Microorganisms Responsible for Degradation of DMS in the FN-200CF-15

Enrichment cultures on DMS were run by inoculating all the colonies that appeared on three agar media with the same dilution ratios as described above. Figure 5 presents an example of DMS degradation in enrichment culture by microorganisms appeared on MW medium. Owing to the accumulation of sulfate ion, a pH decrease was observed frequently and DMS degradation was highly inhibited as illustrated by Fig. 5B. However, after the adjustment of pH to about 7 with 2*N* NaOH, recovery was also very fast, as illustrated in Fig. 5C. Inhibition of DMS degradation was observed for the fall in pH below 6 for MW culture. In the biological deodorization of DMS using the activated carbon fabric FN-200CF-15 as the carrier of the microorganisms, similar phenomena were observed as shown in Fig. 2.

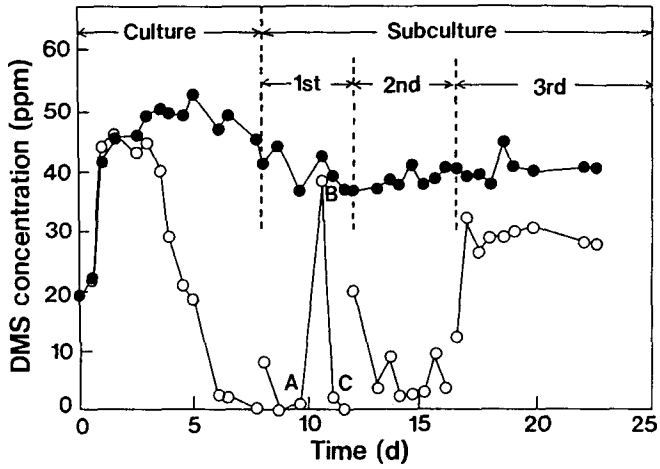

Fig. 5. DMS removal by an isolate isolated from MW medium during enrichment culture. ● Inlet concentration fo DMS; ○ Outlet concentration of DMS.

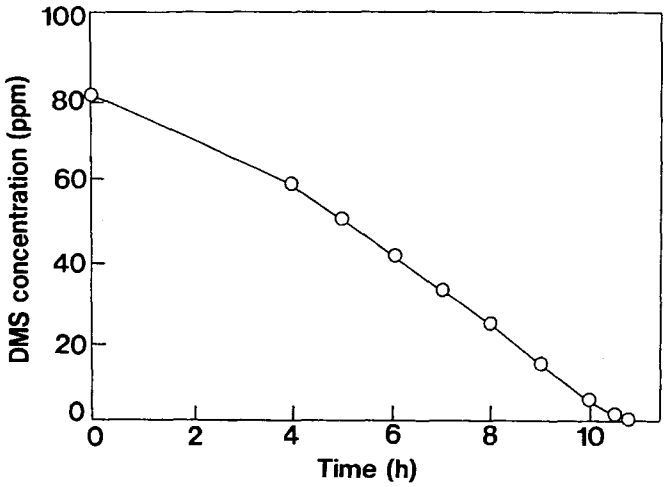

Fig. 6. DMS degradation by strain IM1 (cell number=5.06×10^9) precultured in MW medium for 4 d at 30°C.

No microorganisms appeared on DMSO and NA media degraded DMS, and DMS degrading bacteria appeared only in MW medium. In this medium, two types of colonies that are (a) 1–2 mm diameter in size and whitish yellow in color, and (b) about 4 mm diameter in size and white in color, became dominant. Three colonies of each type were isolated for incubation into the same liquid medium. After proper growth was confirmed, one strain (named as IM1) successfully degraded DMS (Fig. 6) as well as H_2S, MT, and DMDS (Fig. 7). This is the first report of a sulfur oxidizing microorganism enriched and purified on DMS-containing media as an inhabitant in fabric biofilter. As a strain, IM1 successfully

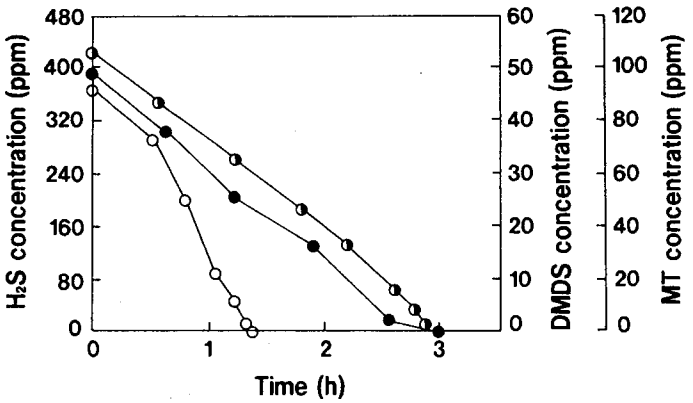

Fig. 7. H_2S, MT, and DMS degradations by strain IM1 (cell number= 5.06×10^9) precultured in MW medium for 4 d at 30°C. ○ H_2S; ◑ MT; ● DMDS.

Table 6
Removal of Volatile Sulfur Compounds

Sulfur compounds	Uptake rate by strain IM1 (g-S/cell/h)	Removal rate in biofilter (g-S/cell/h)
DMS	3.88×10^{-15}	6.36×10^{-15}
H_2S	8.72×10^{-14}	N.D.[a]
MT	1.29×10^{-14}	N.D.
DMDS	1.95×10^{-14}	N.D.

[a]N.D., Not determined.

degraded the volatile sulfur compounds such as DMS, H_2S, MT, and DMDS, a massive inoculation of strain IM1 will enhance the removal rates of these compounds in activated carbon fabric (FN-200CF-15) biofilter. So far, as DMS-degrading bacteria, *Thiobacillus* spp. and *Hyphomirobium* spp. have been reported to degrade DMS as a sole source of energy and/or carbon (*9–13*). Strain IM1 was not like *Hyphomicrobium* sp. from morphological investigation. Further experiment for its identification is in progress.

Table 6 shows uptake rates of DMS and other volatile sulfur compounds by strain IM1 which were calculated from the slopes in Figs. 6 and 7. DMS removal rate in the FN-200CF-15 biofilter based on the cell number (g-S/cell/h) is also shown, which was calculated from the cell number that appeared in MW medium (Table 5), and the DMS removal rate (R=1.97 g-S/kg-dry fab.·d) measured just before counting the cell number. These two values of strain IM1 were not so different, indicating that the strain IM1 may be the dominant microorganism responsible for degradation of DMS in the FN-200CF-15 biofilter.

In conclusion, we have demonstrated a new packing material, activated carbon fabric FN-200CF-15, for the improvement of DMS removability in

a biological deodorizing system. This fabric, which is light, flexible, and less microbially degradable, has relatively larger surface area, providing broader enrivonmental conditions for the inhabitation of microorganisms. The larger surface area reflecting the larger number of microorganisms inhabiting this fabric seems to have better removal efficiency of DMS. Therefore, the activated carbon fabric FN-200CF-15 is one of candidates for the carrier of microorganisms in a practical biological deodorizing system of packed bed reactor.

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