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Biological treatment of gaseous emissions containing dimethyl sulphide generated from pulp and paper industry

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HIGHLIGHTS

- Work carried out with live gaseous emission.
- Experimented with low concentration of the DMS.
- Seeded pure culture for DMS degradation but existed mixed culture in the system.

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ABSTRACT

A bench scale biofilter packed with compost and wood chips seeded with potential DMS degrading culture (*Bacillus sphaericus*) could efficiently remove DMS from ambient air with removal efficiency (RE%) of 71 ± 11 at an effective bed contact time (EBCT) of 360 ± 20 s with loading rate in the range of 4–28 $g_{DMS}/m^3/h$. Further, the same biofilter operated for the treatment of vent gas generated from a P&P industry indicated DMS removal of 61 ± 18% at optimal EBCT of 360 ± 25 s with a loading rate in the range of 3–128 $g_{DMS}/m^3/h$.

1. Introduction

Air emissions from the Pulp and Paper (P&P) industry contain mainly reduced sulfurous compounds (RSCs) which have health and environmental implications (Giri et al., 2010; Chan, 2006). Air emission from P&P industries are treated through physico–chemical process which are cost intensive (Chan, 2006). The biological processes are compatible with the environment. Biofiltration has been a potential cost-effective alternative treatment of mixture of the reduced form of sulfur constituents also known as RSC (Giri et al., 2010; Chan, 2006; Delhomenie and Heitz, 2005; Shareefdeen and Singh, 2005). The biofiltration of DMS in simulated waste gas has been reported in the literature showing variation in the performance of the system (Giri et al., 2010; Chan, 2006; Delhomenie and Heitz, 2005; Shareefdeen and Singh, 2005). RSC biofiltration generates acid, which reduces the pH of the packing medium thereby affecting the biodegradation (Shareefdeen and Singh, 2005; Christen et al., 2002; Maestre et al., 2007). In traditional biofilters without water recirculation, by-products of degradation of reduced sulfur compounds drop the pH of the biofilters. Some of the researchers have reported DMS degradation using methanol for co-metabolism with improved biodegradation of DMS (Zhang et al., 2006, 2007a,b, 2008; Darracq et al., 2010). In the present investigation the ambient air and live vent gas from a P&P industry containing DMS along with other traces of RSCs have been treated in a biofilter packed with wood chips and compost, and seeded with microorganism *Bacillus sphaericus*. The results on these aspects are presented and discussed in this paper.

2. Methods

2.1. Pulp & Paper industry

Pulp & Paper industry was selected for detailed characterization of industrial emissions containing RSCs. The Industry is located in Vidarbha Region 19°57′N 79°18′E19.95°N 79.3°E19.95; 79.3), Maharashtra, India with a paper manufacturing capacity of 2740 MT/day. The Industry located in Vidarbha Region operates with bamboo as raw material for production of pulp and paper. The Industry located in Vidarbha Region, Maharashtra was selected for the investigations due to better experimental logistics.

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2.2. Culture used

The seed culture of *B. sphaericus* strain used for this study was isolated from the garden soil using enrichment technique. This microorganism was identified morphologically and biochemically as per Bergey's manual and using molecular techniques. Isolated *B. sphaericus* has been used in the previous study for the treatment of simulated waste gas containing DMS indicated effective removal of DMS (65–70% at EBCT of 384 s); therefore, the same culture was used as a starter seed for the biofilter inoculation (Giri et al., 2010). The seed culture was stored at 4 °C in oxygen-free vials no longer than 4 months before use. The Genome Bio Technologies PVT Ltd. Pune, India maintains the strain. Culture was grown in nutrient broth medium under shaking condition prior to harvesting of biomass, resuspended in fresh nutrient medium, and seeded in the packing medium during the start-up of the biofilter.

2.3. DNA isolation, purification and tm calculation

DNA isolation was done using conventional CTAB method and extracted DNA was made RNA free by enzymatic treatment (Alexandra Worden, 2009). The RNase was then removed by organic extraction prior to the work. For determining the melting temperature, the DNA was dissolved in 1× saline sodium citrate (SSC) buffer at a final concentration of 20 μg/mL The DNA solution was then subjected to incremental increase in temperature using a temperature-regulated water bath and the range of temperature (25–85 °C) corresponding to the hyper chromatic shift was determined. The midpoint was identified and noted as the melting temperature.

2.4. Molecular characterization of isolated potential culture for degradation of DMS

Native DNA molecules usually denature within a very small increment of temperature. In fact, thermal denaturation of DNA is often designated as melting. DNA specimens from different cell types have characteristically different melting points, defined as Tm, the temperature at the midpoint of the melting curve. Tm increases in a linear fashion with the content of G-C base pairs, which have three hydrogen bonds and are more stable than A-T base pairs. The higher the content of G-C base pairs, the more stable the structure and more thermal energy required to disrupt it. Careful determination of the melting point of the DNA specimen, under fixed condition of pH and ionic strength, can give remarkably good estimate of its base composition.

2.5. Formula for % G+C calculation

$$\%(G + C) = 2.44\,(Tm - K),$$

where K is a constant depending on the solvent (68 °C).

2.6. Biofilter setup and continuous operation

In this study the treatment of ambient air and vent gas containing low concentration of the DMS (0.31–6.81 ppm_v) was carried out in the selected P&P Industry. A schematic of the experimental setup is shown in Fig. 1. The biofilter was constructed from a clear PVC pipe 60 cm long and 10 cm in internal diameter. The porous packing material for the bed was cow dung and wood chips (60–65% porosity). The packing material shows slow release of mineral nutrients as the cow dung has inherent nutrients. As the packing medium gets moistened, it releases nutrients slowly for the microorganisms. The packing material had an average diameter of particles of 2 mm. The active bed height was 55 cm, and thus, the bed volume was 12 L (Table 1).

Biofilm was established in the biofilter following inoculation with grown biomass from *B. sphaericus*. Concentrated biomass (600 mL; 2 g dry biomass/L) was mixed with the bed medium prior to addition to the biofilter. A phosphorus nutrient mineral medium was used in the biofilter. It contained (g/L) KH_2PO_4 (0.615 g); K_2HPO_4 (0.315 g); NH_4NO_3 (0.5 g); $MgCl_2.6H_2O$ (0.2 g); $FeCl_3$ (Anhydrous) (0.001 g) and 2 mL/L of a trace elements solution (Giri et al., 2010). The feeding rate of the mineral medium was 100 mL/day. Dilute NaOH solution (0.1 M) was sometimes added manually to adjust the pH and remove the sulfate in the biofilters whenever the pH of the bed dropped below 6. The system was operated initially in a closed loop with feed of ambient air containing DMS drawn from the vicinity of P&P industry. In the later phase of the study, the biofiltration of ambient air and vent gas containing DMS under continuous flow condition was investigated over a period of more than 156 days (121 days with ambient air +35 days with the vent gas) and the observations were made on daily basis. The biofilter was subjected to an identical airflow rate in the range of 1.5–2.5 L/min, providing an EBCT of 288–480 s in the biofilter during the assessment of EBCT with a syringe pump (Watson Marlo Company). An EBCT of 360 s was optimum; therefore the further experiments were conducted at this EBCT. Ambient air containing DMS was fed to the biofilter located in a P&P Industry at a concentration in the range of 0.77–6.81 ppm, corresponding to a mass loading rate in the range of 4–28 $g_{DMS}/m^3/h$. Similarly the vent gas containing DMS was also fed to the same biofilter in separate set of experiments and the system was operated for a period of 35 days. The temperature of the biofilter was maintained at 30 ± 2 °C with moisture content in the range of 60–80%. The samples of compost packed in biofilter were collected, mixed, and analyzed for microbial status in terms of total count and specific count by adopting standard methods (APHA, AWWA, WEF, 2005). The mixed sample was suspended in a pre-determined volume of a solution of phosphate buffer and kept on a rotary shaker for 30 min. The supernatant of the suspended samples was used to determine the total bacterial count and specific count of DMS-degrading microorganisms present in the system by spreading on nutrient agar and specific agar plates containing DMS. Further, the collected solid compost samples from the biofilter were monitored for pH and moisture content. Thus the biofilter was operated on a continuous feed basis and the parameters, viz. startup time of the biofilter for treatment of DMS, EBCT, DMS loading at optimal EBCT, and requirement of moisture content for the packing medium for effective biotreatment, were evaluated. Changing the input DMS concentration through appropriate dilution of the ambient air at optimal EBCT varied the loading of DMS. During the assessment of the moisture requirement for the packing medium of the biofilter, manipulating the irrigation rate of the nutrient medium on the biofilter varied the moisture content of the system.

2.7. Chemicals and basal medium used

DMS (>99.0%), K_2HPO_4, KH_2PO_4, NH_4Cl, $MgCl_2.6H_2O$, yeast extract and 1.0 mL/L of trace elements (di-sodium ethylene diamine tetra acetic acid, $ZnSO_4$ $7H_2O$, $CaCl_2$ $2H_2O$, $MnCl_2$ $4H_2O$, cobaltous chloride (hexa hydrate), ammonium molybdate (tetra hydrate), $FeSO_4$ $7H_2O$, $Cu(SO_4)_2$, and NaOH were purchased from M/s. Aldrich Co., Germany. The basal agar medium was supplemented with yeast extract (0.1% w/v) for the evaluation of total count of the microorganisms of the biofilter unit, while for the specific count; the medium yeast extract was replaced with DMS.