Microbial Biofilters: A Clean Air Solution

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Abstract

The urbanization in India over the past few decades has led to an increase in population and, consequently, pollution. In many cities, air pollution has become a major concern, with CO_2, CO, and SO_2 being the primary pollutants. This review investigates the potential of microbes such as *Bacillus mucilaginosus*, *Clostridium aceticum*, and *Desulfovibrio desulfuricans* for the preparation of biofilters. Biofilters are technical applications that use the biofiltration process to remove odorous compounds and other pollutants from waste air, such as greenhouse gases. Pollutants are "consumed" by microorganisms in a biofilter and reduced into biomass, water, and CO_2, allowing the filter material to replenish itself constantly. *B. mucilaginosus*, *C. aceticum*, and *D. desulfuricans* have shown the ability to absorb CO_2, CO, and SO_2 from the atmosphere. *Bacillus mucilaginosus* can absorb and fix CO_2 from the atmosphere using carbonic anhydrase secreted by the bacteria. *C. aceticum*, heavily inhibited by CO, achieved continuous CO conversion of over 70% in a membrane bioreactor, resulting in space-time yields of up to 0.85 gL-1 hr-1 acetate. *D. desulfuricans*, when cocultured with floc-forming anaerobes, converted SO_2 to H_2S primarily and eventually to elemental sulphur.

Keywords: *Bacillus mucilaginosus, Clostridium aceticum, Desulfovibrio desulfuricans*

Introduction

Carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and other greenhouse gases have dramatically increased in the atmosphere over the last few decades due to anthropogenic activities such as urbanization, industrialization, deforestation, and the combustion of fossil fuels. These greenhouse gases trap heat in the atmosphere, contributing to climate change, pollution, and global warming. Long-lived greenhouse gases have increased total radiative forcing (the warming influence on climate) by 43% since 1990, with CO_2 responsible for around 80% of this increase (Lindsey & Dlugokencky, 2020). From 1850 to 2018, fossil fuel combustion emitted 440 Pg C (1 Pg C = 10^15 g C) as CO2. In 2019, global atmospheric CO_2 reached a new record high of 409.8 ppm, a 2.5 ppm increase from 2018, and the global atmospheric CO_2 concentration was 417 ppm in June 2021, an increase of 3.5 ppm each year from 2019 (Lindsey & Dlugokencky, 2020).

SO_2 is commonly employed as a marker for gaseous sulphur oxides (SOx) due to its low atmospheric concentration. It is emitted from various sources, predominantly the combustion of fossil fuels. In the United States, sulphur dioxide emissions have declined dramatically over the last five decades, with a 95% reduction from 31.2 million tonnes in 1970 to 1.8 million tonnes in 2020 (Tiseo, 2021). India, however, remains the top emitter of anthropogenic SO_2 emissions, contributing 21% of global emissions in 2019 (Koshy, 2020; Dahiya & Myllyvirta, 2019).

Biofilters

A biofilter is a type of air pollution management device that uses microorganisms to biologically break down odour and other volatile air pollutants in waste air streams. The microorganisms reside on the surface of the biofilter material and in a thin water film that surrounds it. Contaminated air is progressively circulated through the biofilter material during the biofiltration process. The contaminants are absorbed into the water film after being adsorbed by the filter material's surface. Microorganisms then metabolize these pollutants, producing energy, biomass, and metabolic end products, primarily CO_2 and H_2O. This method decomposes the contaminants completely without producing any dangerous by-products.

Bacillus mucilaginosus

Bacillus mucilaginosus is a gram-negative bacterium commonly found in soil. It can absorb atmospheric CO_2 and fix it through bacterial metabolism, aided by the enzyme carbonic anhydrase. Studies have shown that carbonic anhydrase can reversibly catalyze CO_2 hydration, facilitating CO_2 sequestration from the air (Zhang et al., 2011). When cultured in a medium containing limestone, both the Ca^{2+} concentration and carbonic anhydrase activity increased in tandem with the amount of limestone in the medium. This bacterium can capture atmospheric CO_2, convert it to bicarbonate and H^+ ions, and fix it through its metabolism, providing a new technique for atmospheric CO_2 sequestration (Zhang et al., 2011).

Clostridium aceticum

Clostridium aceticum is an obligate anaerobe that inhabits soil and the intestinal tracts of animals. This bacterium can use CO as the only carbon and energy source for chemolithoautotrophic carbon fixation but has low tolerance to high CO concentrations. In batch procedures, *C. aceticum* produced autotrophic ethanol with CO as a substrate (Sim et al., 2007). CO inhibition kinetics of *C. aceticum* revealed significant CO inhibition at an optimal CO partial pressure of 5.4 mbar in the gas phase. In a continuously operating stirred-tank bioreactor with immersed membranes and 100% cell retention, continuous CO conversion of over 70% was achieved, resulting in space-time yields of up to 0.85 gL-1 hr-1 acetate (Sim et al., 2007).

Desulfovibrio desulfuricans

Desulfovibrio desulfuricans is a gram-negative sulphate-reducing bacterium found in both freshwater and marine environments, as well as in soils and animal digestive tracts. This bacterium can reduce sulphur dioxide to hydrogen sulphide (H_2S) when cocultured with floc-forming anaerobes, resulting in a sulfate-reducing floc that can be recovered for recycling (Selvaraj & Sublette, 1995). The maximal specific activity for SO_2 reduction in these cultures was 9.1 mmol in terms of the dry weight of *D. desulfuricans* biomass. The stoichiometry for the electron donor was 15.5 mg of soluble COD/mmol of SO_2 reduced (Selvaraj & Sublette, 1995).

Applications

The use of biofilters has a broad range of applications in environmental management and pollution control. Biofilters are employed in industries such as waste management, chemical manufacturing, and food processing to treat odorous emissions and volatile organic compounds (VOCs). They are also used in municipal wastewater treatment plants to control odour emissions

Feasibility

The feasibility of using *Bacillus mucilaginosus*, *Clostridium aceticum*, and *Desulfovibrio desulfuricans* for biofiltration depends on several factors, including the availability of these microorganisms, the cost of maintaining optimal growth conditions, and the efficiency of pollutant removal.

- *Bacillus mucilaginosus* shows promise for CO_2 sequestration due to its ability to fix CO_2 using carbonic anhydrase. The challenge lies in scaling up the process and ensuring the continuous supply of limestone and other necessary nutrients (Zhang et al., 2011).
- *Clostridium aceticum* demonstrates significant potential for converting CO to acetic acid. However, its sensitivity to high CO concentrations and the need for precise control of environmental conditions may limit its practical applications (Sim et al., 2007).

Desulfovibrio desulfuricans offers an effective solution for SO_2 reduction in industrial settings. The process requires careful management of anaerobic conditions and co-culturing with other microorganisms to achieve optimal results (Selvaraj & Sublette, 1995).

Future Scope

The future scope of using these microorganisms in biofilters involves several research and development directions:

1. **Genetic Engineering**: Enhancing the pollutant-degrading capabilities of these microorganisms through genetic modification could improve their efficiency and resilience under industrial conditions.
2. **Optimization of Culture Conditions**: Developing cost-effective and scalable methods to maintain optimal growth conditions for these microorganisms is essential for large-scale applications.
3. **Integration with Existing Technologies**: Combining biofilters with other air pollution control technologies, such as scrubbers and catalytic converters, could enhance overall efficiency and effectiveness.
4. **Field Trials and Case Studies**: Conducting field trials and documenting case studies in various industrial settings will provide valuable insights into the practical challenges and benefits of using microbial biofilters.

Regulatory Support and Incentives: Government policies and incentives promoting the use of biofilters for air pollution control could accelerate the adoption of these technologies.

Conclusion

This review provides useful information on microbes that can reduce greenhouse gases such as CO_2, CO, and SO_2. *B. mucilaginosus* contains the enzyme carbonic anhydrase which, when cultured with limestone and Ca^{2+} ions, reduces CO_2 to bicarbonates and H^+ ions. *C. aceticum*, with a mixed gas composition of 4% H_2 and 18% Argon, reduces 78% CO to acetic acid. *D. desulfuricans*, when cocultured with floc-forming anaerobes, converted SO_2 to H_2S primarily

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