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Decomposition of taste-and-odor compounds produced by cyanobacteria algae using atmospheric pressure plasma created inside a porous hydrophobic ceramic tube

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HIGHLIGHTS

- Large gas–liquid interfacial area and instant transfer of reactive species to water.
- Effective decomposition of taste-and-odor compounds and cyanobacteria algae.
- Good correlation of the decomposition efficiency to the specific energy input.

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ABSTRACT

This study investigated an underwater plasma water treatment system based on a porous hydrophobic hollow ceramic tube and an alternating current (AC) voltage source, and its application to the decomposition of taste-and-odor compounds originated from algae. The taste-and-odor compounds investigated were geosmin and 2-methyl isoborneol (2-MIB), and the decomposition of algae was carried out on cyanobacteria. The features of the present atmospheric-pressure plasma system employing a porous ceramic tube are large gas–liquid interfacial area due to the formation of numerous plasmatic gas bubbles and instant transfer of short-lived reactive species to water through the micro-pores of the ceramic tube right after the generation. The present plasma process was found to effectively decompose not only the taste-and-odor compounds but also the cyanobacteria algae. Both geosmin and 2-MIB were decomposed more rapidly in the raw river water than in the distilled water. The intermediate products resulting from the decomposition of the taste-and-odor compounds were identified, which showed that geosmin and 2-MIB underwent ring opening and subsequent bond cleavage at multiple sites. The specific energy inputs (SEIs) for 90% decomposition of algae ranged from 3.4 to 8.4 kJ L^{-1} for the initial concentration range of 129–1596 μg L^{-1}. The decomposition efficiencies of the taste-and-odor compounds were well correlated with the SEI.

1. Introduction

Increased water temperatures and more frequent droughts due to global warming aggravate eutrophication of fresh water lakes and rivers, which in turn aids algae blooms, making it increasingly difficult to control the quality of water. Particularly, cyanobacteria, better known as blue–green algae, cause various environmental problems such as depletion of dissolved oxygen and production of toxins and taste-and-odor-compounds, attracting a lot of attention recently [1,2]. Cyanobacteria forming in lakes and rivers comprise cells capable of housing naturally produced poisons called cyanobacterial toxins. These toxins are usually released into water when the cells rupture or die. Primary taste-and-odor-compounds produced by cyanobacteria include geosmin and 2-methylisoborneol (2-MIB) that are semi-volatile metabolites. Geosmin and 2-MIB emit strong scent, and the odor detection threshold in humans has been reported at concentrations as low as 1.3 ng L^{-1} for geosmin and 6.3 ng L^{-1} for 2-MIB [3]. In this context, methods toward effective abatement of these compounds need to be explored. Meanwhile, microcystins (MCs) are the most common cyanobacterial toxins, and they can be very toxic for animals including humans, causing serious damage to the liver and strongly inhibiting a class of enzymes known as protein phosphatases. There are over 80

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Table 1
Raw river water quality.

Sampling locations	Cyanobacteria (μg L^{-1})	Chlorophyll-a (μg L^{-1})	2-MIB (ng L^{-1})	Geosmin (ng L^{-1})	Na^+ (mg L^{-1})	Ca^{2+} (mg L^{-1})
Seungchon Weir (SW)	98	129	24.9	1.6	25.2	21.6
Juksan Weir (JW)	214	239	86.9	2.0	18.7	19.4
Yeongsanpo (Y)	1460	1596	89.8	2.5	19.6	20.4
Sampling locations	T-P (mg L^{-1})	T-N (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	Turbidity (NTU)	TOC (mg L^{-1})
Seungchon Weir (SW)	0.03	0.1	35.7	18.5	24.8	5.5
Juksan Weir (JW)	0.07	0.4	23.5	16.0	55.8	18.7
Yeongsanpo (Y)	0.29	3.5	26.2	16.0	214	31.6

Table 2
Summary of GC/MS analytical conditions.

Parameters	Conditions				
Instrument	Agilent Tech-7890 GC-5975 inert MSD-PAL system				
Ionization	70 eV				
Acquisition	Selected ion monitoring (SIM) mode				
Oven	Temp. (°C)	40	60	215	300
	Holding time (min)	5	5	0	0
	Rate (°C min^{-1})	15	15	30	
Column	DB-1 ms (340 °C: 30 × 250 × 0.25 μm)				
Flow rate	1 mL min^{-1} (split)				
Mass	Geosmin (97,112,125), 2-MIB (95,108,135)				

known toxic variants of MCs, even though 6 variants such as MC-LR, MC-LA, MC-YR, MC-RR, MC-LF and MC-LW account for the most part in nature. MC-LR is often mentioned as the most frequently occurring microcystin, and the World Health Organization (WHO) guideline for MCs in drinking water, based on MC-LR, is reported to be 1 μg L^{-1} (ppb) [4–6]. Anatoxin-a, also produced by cyanobacteria, exhibits acute neurotoxicity leading to paralysis and respiratory arrest in exposed animals. Anatoxin-a may pose a serious threat to humans and animals due to its highly poisonous character and potential existence in drinking water.

Geosmin and 2-MIB have small Henry's law constants, i.e., low volatilities, indicating that air stripping method is not viable.

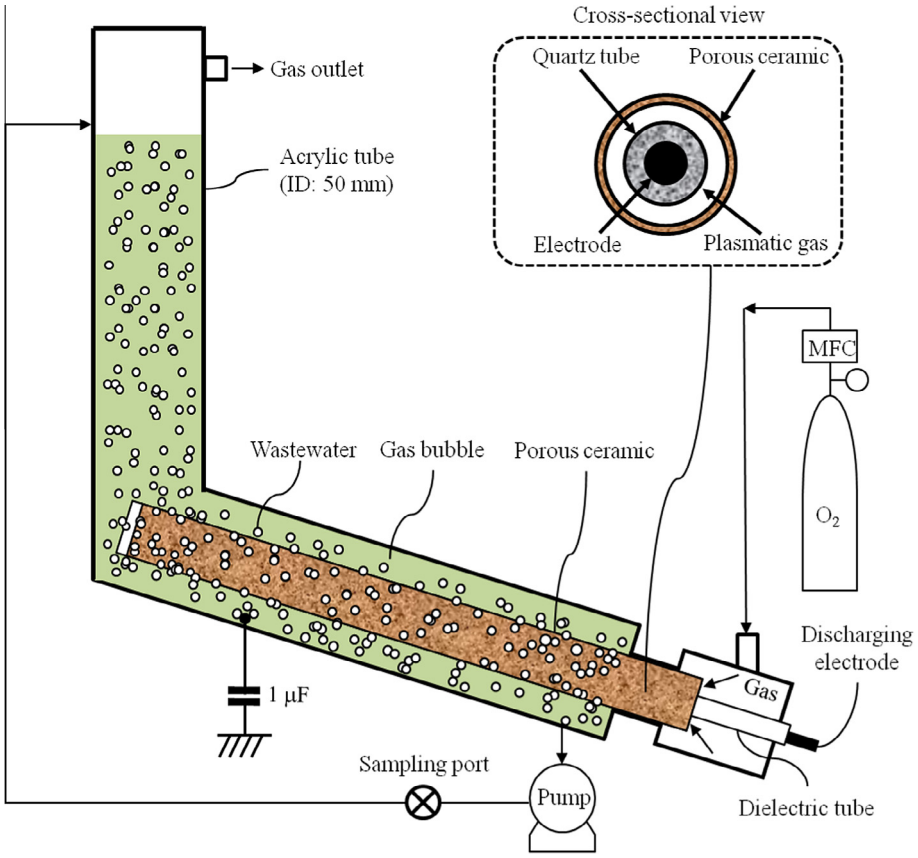

Fig. 1. Schematic description of the experimental apparatus for decomposing the taste-and-odor compounds and algae.