Separation and Purification Technology 77 (2011) 87–93

Contents lists available at ScienceDirect

Separation and Purification Technology

journal homepage: www.elsevier.com/locate/seppur

Simultaneous removal of odors, airborne particles, and bioaerosols in a municipal composting facility by dielectric barrier discharge

Chul Woo Park[a], Jeong Hoon Byeon[b], Ki Young Yoon[c], Jae Hong Park[a], Jungho Hwang[a,d,*]

[a] School of Mechanical Engineering, Yonsei University, Seoul 120-749, Republic of Korea
[b] LCD Division, Samsung Electronics Co., Ltd., Yongin 446-711, Republic of Korea
[c] Exhaust Emission Engineering Team, Hyundai Motor Company, Hwaseong 445-706, Republic of Korea
[d] Yonsei Center for Clean Technology, Yonsei University, Seoul 120-749, Republic of Korea

ARTICLE INFO

Article history:
Received 3 August 2010
Received in revised form
18 November 2010
Accepted 22 November 2010

Keywords:
Dielectric barrier discharge (DBD)
Municipal composting facility
Odors
Airborne particles
Bioaerosols

ABSTRACT

The process of waste decomposition releases odors, airborne particles, and bioaerosols; therefore, air quality control at composting facilities is very important to the health of workers and the effective operation of such facilities. Because dielectric barrier discharge (DBD) produces chemical species, it has been used to remove undesired species interesting for environmental applications. In this study, a DBD reactor was applied to a composting facility to simultaneously remove odors, airborne particles and bioaerosols. The power consumption required was below 18.9 W when the flow volume of the pollutant gas was 0.2 L and the concentrations of ammonia, amines, airborne particles, and bioaerosols were 150 (or 75) ppm, 140 ppm, 2.1×10^8 particles/m^3, and 1.1×10^4 CFU/m^3, respectively. The removal efficiency of contaminants in the air increased as the specific energy densities (SED) increased, with removal efficiencies of up to 80% and 76% being achieved for ammonia and amines. Moreover, the removal efficiency of the overall airborne particles was 75% when 113 J/L of SED was employed, while the bioaerosols removal efficiency was 89% when 38 J/L of SED used.

1. Introduction

The process of waste decomposition in composting facilities releases a variety of odors, airborne particles, and bioaerosols [1–6]. They cause infections or irritations to humans, especially to sensitive or sick people [2,4]. While some of the odors are not considered to cause health problems directly, they may well be associated with diseases and negative health effects, which may cause defensive reactions of people due to psychological effects [7]. For the reasons, adequate air quality control in composting facilities is very important to the health of workers and surrounding residents [8].

It is well known that dielectric barrier discharge (DBD) produces highly non-thermal plasma in a controllable way at atmospheric pressure and temperature [9]. DBD technologies have high decomposition efficiency and ability to be tuned by adjusting the power level to match the source flow, concentration and ozone generation, yet require no additional disposal [1]. Until recently, DBD has primarily been used as an effective ozone generator [10–12]. However, researchers are now investigating the feasibility of using DBD for a wide range of fields. Since DBD serves as a chemical reactor that produces active chemical species under various reactions, it has been used to remove various undesired species interesting for environmental applications.

The atmospheric destruction of odorous gases by DBD occurs via the direct collision of electrons with gas molecules. Also a small amount of ozone or nitrogen oxides are generated from air by the discharge, and these compounds then react with odorous gases [13–16]. To collect airborne particles, the particles are first charged in DBD, after which they are collected on DBD plates [17]. Generally, bioaerosols are sterilized by physical or chemical processes in the DBD reactor. The physical process proceeds by positive and negative ions in the discharge's streamer, while the chemical process is accomplished by ozone and atomic oxygen produced in the DBD [18].

Traditional odor control methods such as wet scrubbing, active carbon adsorption, ozone oxidation, and biofiltration are limitative technically and economically for the abatement of odor from industry facility. Non-thermal plasma techniques are typically characterized by high removal efficiency and relatively low power consumption [19,20]. Odors emitted from animal houses and wastewater treatment plants can be removed by plasma reactors such as a ferroelectric packed-bed plasma reactor [1] and a pulse corona reactor [15].

Compared to other non-thermal plasma reactors, DBD reactor has advantages of easy operation and high efficiency in generating

* Corresponding author at: School of Mechanical Engineering, Yonsei University, Seoul 120-749, Republic of Korea. Tel.: +82 2 2123 2821; fax: +82 2 312 2821.
E-mail address: hwangjh@yonsei.ac.kr (J. Hwang).

1383-5866/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.seppur.2010.11.024

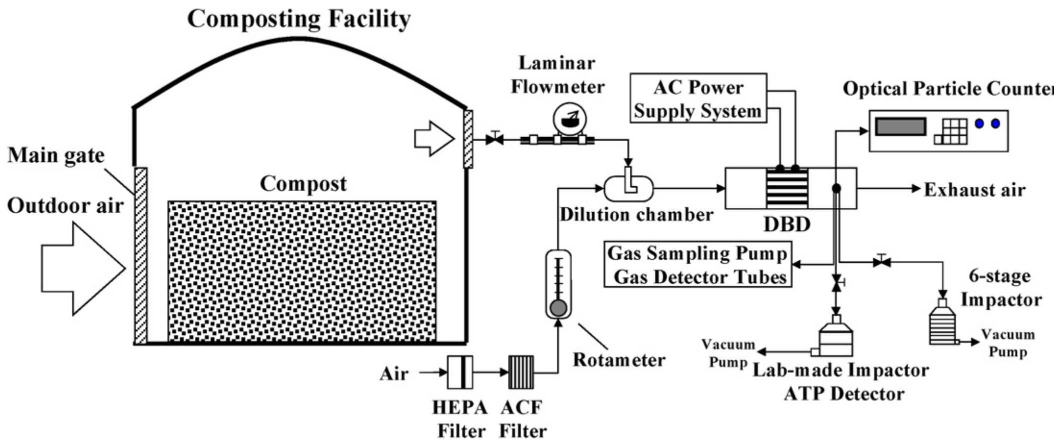

Fig. 1. Layout of the composting facility and experimental setup.

gas phase radicals [16]. Xia et al. [16] reported that in a DBD reactor ammonia was removed from gas streams within 0.1 s. Chen et al. [19,20] investigated the effects of humidity and balance gas mixture on energy yield and conversion efficiency of dimethyl sulfide and dimethylamine. Kim et al. [21] attempted to remove nitrogen oxide by a DBD reactor, and carried out numerical simulations to understand the observed streamer dynamics in the DBD reactor. Chang and Chang [22] performed a study on removing toluene and methyl ethyl ketone by a DBD reactor. In their study, the effects of gas temperature, O_2 content of gas, and water vapor content of gas on removal efficiency were reported, and simultaneous removal of toluene and methyl ethyl ketone was attempted. In Chang and Lee [23], the effectiveness of applying DBD plasmas for removal of formaldehyde was experimentally evaluated with a laboratory-scale apparatus. The removal efficiency of 97% was achieved with an applied voltage of 19 kV. Ye et al. [24] studied the destruction of gaseous benzene in both laboratory-scale and scale-up DBD reactors. Moreover, DBD technologies were recently evaluated to determine if they could be used for the collection of submicron particles and removal of gaseous contaminants. Byeon et al. [17] and Jidenko and Borra [25] attempted to remove submicron particles, and Kuroda et al. [26] investigated the simultaneous reduction of carbon particles and NO_x by DBD reactor. In addition, sterilization of *Escherichia coli* and *Fusarium oxysporum* with a DBD reactor was reported by Choi et al. [18] and Takayama et al. [27], respectively. However, a care is needed for using a DBD reactor, since the reactor can generate unwanted by-products such as ozone and nitrogen oxides [10,11,14], and produce high power peaks which may induce problems of electromagnetic hazards [28].

In our previous study [29], we studied the feasibility of the use of our lab-made DBD reactor in removing gaseous contaminants and airborne particles, separately. Toluene was selected as model gaseous contaminant, while a mixture of sodium chloride and dioctyl sebacate particles was selected as model airborne particles. In this study, we attempted to simultaneously remove odors, airborne particles, and bioaerosols from a municipal composting facility using a scale-up version of the lab-made DBD reactor. Ammonia and amines were selected as representative odor gases since strong ammonia and amines related odors are commonly produced during composting processes [30,31].

2. Materials and methods

Experiments were conducted at a full-scale composting facility in Dangjin-Gun, Korea, with a treatment capacity of 24 tons of food waste per day. The experimental schematic is shown in Fig. 1. The contaminated air emitted from the composting facility was diluted with particle-free and odor-free air that was delivered through a HEPA filter and an activated carbon fiber (ACF) filter. Next, the diluted mixture was treated by passing it through a DBD reactor at residence times of 0.35, 0.52, 0.69, 1, and 2.07 s. Under all test conditions, the gas temperature and humidity were approximately 25 °C and 55%, respectively.

The DBD reactor consisted of sixteen-parallel plate electrodes that were configured in an alternating fashion, with one electrode being grounded and the next one received high AC voltage. The gap spacing between any two electrodes was 5 mm. Each electrode was made of 0.03 mm thick copper foil (20 mm of streamwise length and 125 mm of spanwise length) sandwiched between two 0.3 mm thick dielectric plates (ceramic plates, 30 mm of streamwise length and 135 mm of spanwise length). Fig. 2(a) shows the voltage–current characteristics for frequencies of 60 and 120 Hz. Higher frequencies resulted in higher discharge current. The discharge currents were 0.2–1.7 and 0.2–2.25 mA for frequencies of 60 and 120 Hz, respectively. The power consumption was below 18.9 W when the flow volume of the pollutant gas was 0.2–L and the concentrations of ammonia, amines, airborne particles, and bioaerosols were 150 (or 75) ppm, 140 ppm, 2.1×10^8 particles/m^3, and 1.1×10^4 CFU/m^3, respectively. The voltage and current were measured using a two-channel digital oscilloscope (TDS 1012, Tektronix, USA) and their root-mean-square (RMS) amplitude values are indicated in Fig. 2(a). For these frequencies, the transition to arc occurred at voltages slightly higher than 9.5 kV. Fig. 2(b) shows the temporal voltage (rectangular) profile when the RMS voltage and frequency were 9 kV and 60 Hz, respectively. The DBD reactor was performed stably without thermal cracking of the electrodes.

The concentration of odorous gas was measured at a location downstream of the DBD reactor [31] using gas detector tubes. A gas sampling pump (GV-100S, Gastec Corporation, Japan) was used in conjunction with appropriate detector tubes, which changed color in response to the presence of odorous gas. The odorous gas removal efficiency (RE_{odor}) is defined by

$$RE_{odor} = 1 - \frac{C_{odor}}{C_{odor,0}} \quad (1)$$

where $C_{odor,0}$ is the initial gas concentration under each test condition when the power applied to the DBD reactor is turned off and C_{odor} is the concentration measured at a location downstream of the DBD reactor when the power applied to the DBD reactor is on.

The concentrations of airborne particles were measured at a location downstream of the DBD reactor using an optical particle counter (Portable Aerosol Spectrometer #1.109, Grimm Aerosol Technik GmbH & Co. KG, Germany) over 2 min (interval time: 6 s). The optical particle counter operates on the basis of optical light