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Charging processes of particles produced from dilute xylene in air under electron beam irradiation

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Abstract

The yields of charged particles relative to those of total particles from *o*-xylene based on their number and volume concentrations (η_N and η_V) and the polarities of the charged particles of products were examined under EB irradiation without and with external fields applied to irradiated air mixtures, which are the conditions with bipolar ions and unipolar ions, respectively. The η_N and η_V by bipolar ions were constant at 31–37% and 56–59%, respectively, independent of dose and initial xylene concentration, while those by unipolar ions were 48–55% and 91–93%, respectively.

Keywords: Charging; Particles; Aromatic hydrocarbons; Electron beam; Decomposition; Xylene; Unipolar

1. Introduction

Free radicals and ions at high concentrations are produced from the reaction of energetic electrons with atmospheric air components at ambient temperature under electron beam (EB) irradiation (Willis et al., 1970; Fehsenfeld et al., 1971). The oxidation of gaseous organics even at the concentrations of ppmv levels in air are initiated by the free radicals such as hydroxyl and peroxyl radicals as well as oxygen atoms even at shorter times, because the reaction rate constants of these free radicals with organics are 10^{-12}–10^{-13} molecules cm^{-3} s^{-1} (Atkinson, 1985; Herron and Huie, 1973). The EB treatment is accordingly suitable for the oxidation treatment of dilute organics/air mixtures at an extremely high flow rate.

Toxic particles with mobility equivalent diameters (D_Z) of a few tens of nm are produced from aromatic hydrocarbons by EB irradiation of aromatic hydrocarbons/air mixtures (Hakoda et al., 1998, 2006; Hirota et al., 1995, 2000; Prager et al., 2003). The removal of the particles of products from the gas phase is required for the degradation of aromatic hydrocarbons in air mixtures, because of the oxidation-resistance character of particulate products.

The relative ratio of ions to free radicals yields EB irradiation which are higher than those for an electric discharge such as an electro-precipitator, a corona discharge (Burton and Funabashi, 1969). Therefore, the EB is regarded as the source that can produce positive and negative ions (bipolar ions) and free radicals at high concentrations in the atmospheric gases. The high-concentrated ions have the potential to charge the particles of products under EB irradiation. The resulting charged particles can be removed from the gas phase with an electric field. The physical characteristics of the particles such as their charging states, sizes, and concentrations are required for the process design of the efficient removal of the particles from the gas phase.

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In the present work, the characteristics of the particles produced from *o*-xylene at initial concentrations of 10 and 30 ppmv in humid air were studied by their analysis by minimizing their coagulation using a few tens of keV EB generator. The relative ratios of charged to total particles yields by EB-induced bipolar (positive and negative) ions were examined from the difference of the concentrations of total particles in the presence and absence of charged particles. The number concentrations of positively and negatively charged particles of products were also analyzed as a function of mobility equivalent diameter, D_Z, at different doses and initial *o*-xylene concentrations. When an external electric field is applied to an irradiated air mixture under EB irradiation in the same direction as the stream of air mixtures, ions having one polarity (unipolar ions) can be transported along with the charged and neutral particles of particulate products. As a result, the particles seem to be fully charged through the reactions with unipolar ions with less neutralization. In the present work, the relative ratios of charged to total particles yields were also examined under different external electric fields.

2. Experimental

The experiment setup for the charging of the particles of products by bipolar ions under EB irradiation and those by unipolar ions under EB irradiation with applying an external electric field to irradiated air containing 10 and 30-ppmv *o*-xylene (xylene) and 1.0×10^4-ppmv gaseous water will be described in Sections 2.1 and 2.2, respectively.

2.1. Experiments for charging of particles of products by bipolar ions

2.1.1. EB irradiation

The generator of EB with energy of a few tens keV and a stainless-steel irradiation cup (ID 46 mm and H 25 mm) equipped with two tubes (ID 8 mm and OD 9.5 mm) were used for the irradiation of atmospheric air mixtures (Hakoda et al., 2006). The EB generator consists of EB generation tube, vacuum system, and the control unit for high voltage (HV) supplier. The irradiation cup was connected to the EB generation tube to cover its irradiation window (Ti, thickness: 2 μm). The air containing 10- and 30-ppmv xylene and 1.0×10^4-ppmv water vapor, hereafter air mixture, was introduced into the cup at a flow rate of 10 L min^{-1} and irradiated with 50 keV EBs. Electron beams imparted all their energy to the air mixture along the beam path. The temperature of the air mixture was maintained at 298 K during irradiation by the circulation of cooling water outside of the cup. The irradiation cup and the tubing between the irradiation cup and the sampling ports were electrically grounded to inhibit the generation of an electric field from charged particulate products on deposited the tube. The average absorbed dose in the gas mixture was estimated by the chemical reaction of oxygen (O_2) under the same irradiation conditions (Namba et al., 1989; Hakoda et al., 2006). The gas mixture at a flow rate of 10.0 L min^{-1} was irradiated to doses in the range of 2.5–10 kGy.

2.1.2. Analysis of products from xylene

The concentrations of the particles of products in irradiated air mixtures were measured by the scanning mobility particle sizer (TSI, Model 3934 SMPS) consisting of a differential mobility classifier (TSI, Model 3071A) with ^{241}Am as a neutralizer and a condensed particle counter (TSI, Model 3025A). Irradiated air mixtures after being diluted to 1/100 with synthetic air in a dilutor were introduced to the SMPS at a flow rate of 1.0 L min^{-1} for the measurement of the size in the range of 7.23–305 nm. The irradiated air mixtures were introduced to the inlet of the dilutor through electrically grounded copper tube (ID 8 mm and OD 9.5 mm) at a flow rate of 10 L min^{-1}. The residence time of the irradiated air mixtures between the outlet of the irradiation cup and the inlet of the dilution system was estimated to be 0.20 s.

A charged particle collection vessel (CPCV), as shown in Fig. 1, was connected with the outlet of the irradiation cup to examine the relative ratio of charged to total particles yields based on number and volume concentrations (η_N and η_V). The CPCV is a vessel having stainless-steel bi-cylindrical electrodes insulated at a distance of 10.0 mm by Teflon rods. Their surfaces of both electrodes are electropolished. The inner electrodes can be applied to a voltage of at least 3.0×10^3 V without any discharges. The charging rates of particulate products were calculated from the changes in the concentrations of particulate products measured by the SMPS with and without an electric field applied between the inner electrode and the wall of the CPCV. The resident time of air mixture at a flow rate of 10.0 L min^{-1}

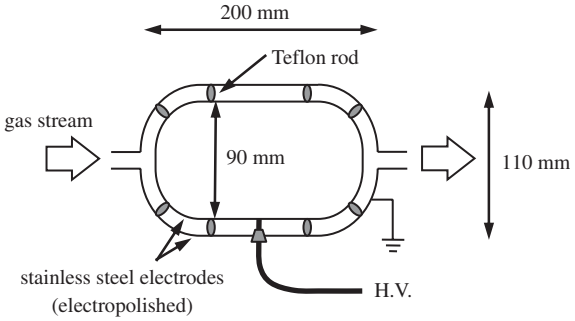

Fig. 1. Charged particle collection vessel (CPCV).