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Efficient catalyst-free removal technique of benzene in air using a vacuum ultraviolet excimer lamp

Benzene (C_6H_6) is a typical VOC (volatile organic compound) pollutant which is widely detected in the atmosphere of both indoor and industrial areas. Especially in indoor environment, it would make a great influence on human health for its high toxicity and carcinogenicity. Therefore, it is highly desired to develop an efficient removal technique of C_6H_6 from the ambient environment. Current methods to remove C_6H_6 from indoor air include plasma oxidation, photocatalytic oxidation, and adsorption by activated carbons. The plasma discharge method is also used in domestic air cleaners for removal of VOCs involving C_6H_6. Active radicals such as O and OH formed by plasma discharge are strong oxidants that degrade C_6H_6 to carbon monoxide and carbon dioxide. However, these radicals also oxidize nitrogen and oxygen simultaneously, respectively generating NO*x* and O_3. Therefore, the development of a new effective removal method of C_6H_6 without toxic NO*x* emission is highly anticipated.

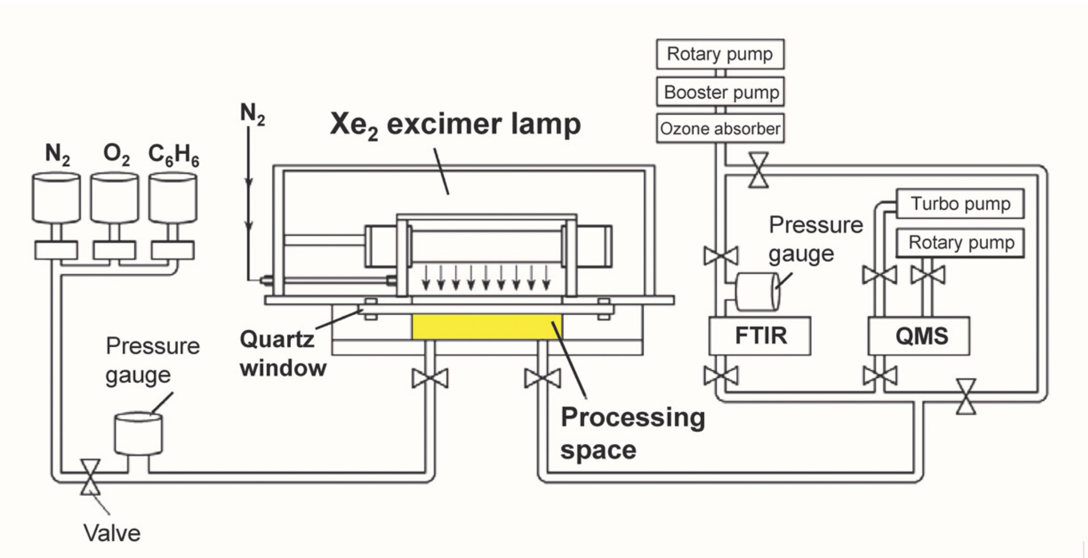

Fig. 1. Schematic diagram of C_6H_6 removal apparatus using a side-on type of 172-nm Xe_2 excimer lamp in air.

We have recently proposed a vacuum ultraviolet (VUV) photolysis using a side-on type of 172-nm Xe_2 excimer lamp as a new promising technique for removal of C_6H_6. The greatest advantage of this method is that no NO*x* emission occurs because N_2 molecules in air cannot be decomposed into active N atoms in the 172-nm photolysis. Other advantages of the VUV photolysis method are that it can operate at a room temperature in air at atmospheric pressure without using expensive novel metal catalysts.

Figure 1 shows a schematic diagram of VUV photolysis apparatus, which consists of a photolysis chamber equipped with a side-on type of Xe_2 excimer lamp and a gas analysis system. Experiments were carried out in a closed batch system or a flow system by observing Fourier transform infrared spectrometer spectra of reagent and products during photolysis.

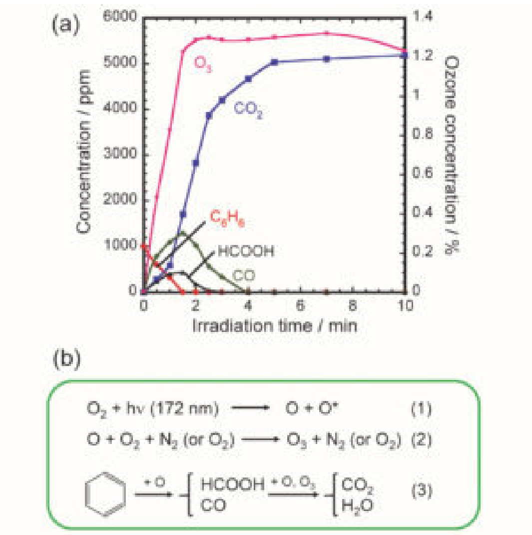

Fig. 2. (a) Dependence of concentrations of C_6H_6, HCOOH, CO, CO_2, and O_3 on the irradiation time under 172-nm photolysis of C_6H_6 in air at atmospheric pressure. (b) Photolysis processes of C_6H_6 in air under 172-nm photoirradiation.

In the batch experiment, C_6H_6 (1000 ppm) in air was finally converted to CO_2 via HCOOH and CO intermediates after 1.5 min photoirradiation (Fig. 2a). When the 172-nm light is irradiated into C_6H_6 (<1000 ppm)/air (O_2: 1-20%=10,000-200,000 ppm) mixtures, incident photons are dominantly absorbed by O_2 through the famous Schumann-Runge continuum. Then, high concentrations of O atoms and O_3 molecules are generated by processes (1) and (2) in Figure 2b. Therefore, not only direct VUV photolysis of C_6H_6 but also reactions of O atoms and O_3 molecules with C_6H_6 can participate in the degradation of C_6H_6. To examine effects of direct VUV photolysis of C_6H_6, C_6H_6 was decomposed in N_2, whereas the contribution of O_3 was studied by observing the $O_3 + C_6H_6$ reaction in the same apparatus. Kinetic model calculations of decomposition processes were also carried out to clarify major oxidation pathways. Experimental and simulation data show that the $O + C_6H_6$ reaction plays a major role in the C_6H_6 removal in the initial degradation stage and O_3 molecules assist oxidation of intermediates to CO_2 (process (3) in Fig. 2b).

By using a flow system, C_6H_6 (200 ppm) was completely removed at a total flow rate of 250 mL/min. The decomposition efficiency of C_6H_6 and the energy efficiency of the excimer lamp in the removal of C_6H_6 changed in the 31−100% and 0.48−1.2 g/kWh range, respectively, depending on the flow rate, the O_2 concentration, and the chamber volume. For the practical use of side-on lamp, effects of such experimental parameters as photon numbers/s, O_2 pressure, and reaction temperature were examined by simulations. These data give valuable information required for the further development of our new technique. If our apparatus can be scaled up for VUV irradiation into a large area, its practical application to removal of C_6H_6 will be possible in the near future.

Masaharu Tsuji, Takashi Kawahara, Keiko Uto, Jun-ichiro Hayashi, Takeshi Tsuji
Institute for Materials Chemistry and Engineering,
and Research and Education Center of Green Technology,
Kyushu University, Kasuga, Fukuoka, Japan

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