

Investigation of 207 nm UV radiation for degradation of organic dye in water

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Abstract

The photo-degradation of organic dye C.I. Acid Red 213 (AR-213) was achieved by 207 nm UV radiation emitted from a planar KrBr* excimer lamp without addition of oxidants at varying initial pH values. Precipitates were found to be generated when the irradiated solution of initial acid pH was adjusted to alkaline pH and they would disappear again when the solution was readjusted to acidic conditions. The efficiency of COD removal was greatly increased after the filtration of precipitates. Both the decolourisation rate and the COD removal rate reached the maximum in the initial pH 2.8 solution. The same phenomenon was also observed for other kinds of dyes. Direct photolysis was the only pathway in degrading dye molecules for both O₂-saturated and N₂-saturated solutions. The by-products formed for initial acidic solution were identified by electro-spray ionisation (ESI) in positive mode and the influence of initial pH on the reaction mechanism of the dye under 207 nm radiation was analysed.

Keywords: 207 nm radiation, direct photolysis, dye, pH

Introduction

The removal of coloured substances from effluents is an important component of wastewater treatment and investigations on the decolourisation of textile dyes have been conducted for a long time. One method for removing organic pollutants is ultraviolet (UV) technologies (Munter, 2001). The most commonly used UV sources for the UV-treatment systems are low- or medium-pressure mercury lamps. However, most chemical bonds cannot be broken directly due to the limited available wavelengths not matching absorption bands of the targeted organic material. Thus the UV degradation process must depend on oxidants such as H₂O₂ and ozone absorbing UV to generate active hydroxyl radicals to attack toxic organics (Neamtu et al., 2002; Shen and Wang, 2002; Koch et al., 2002; Choi and Wiesmann, 2004). However, an excess of oxidants added in the treated solution can interfere with the process (Chen et al., 2004).

Dielectric barrier discharge (DBD) driven excimer lamps are versatile lamps. Depending on the filling gas, they may emit radiation into narrow-band or quasi-monochromatic spectrum with desired specific wavelength (Mildren et al., 2001; Hirose et al., 2002; Falkenstein and Coogan, 1997; Zhang and Boyd, 1996). The entire UV spectral region can be covered with possible excimers (Xe₂^{*}, F₂^{*}, Cl₂^{*}, Br₂^{*}, I₂^{*}, ArBr^{*}, ArCl^{*}, ArF^{*}, KrI^{*}, KrBr^{*}, KrF^{*}, XeI^{*}, XeCl^{*}, XeF^{*}) with wavelength from 172 nm to 317 nm (Kogelschatz, 2003). Since many photo-physical and photochemical processes are initiated by specific, narrow-band wavelength, DBD-driven excimer UV light sources could improve or solve specific photo-physical or photochemical processes without the addition of oxidants.

This study investigated the removal of dyes in water using the planar KrBr* excimer lamp that emits 207 nm radiation since most organic dyes and their aromatic and naphthalene intermediates exhibit strong absorption in the vicinity of 200 nm wavelength. The reaction mechanisms and by-products of direct photolysis of organic dye under 207 nm radiation were studied and the results are presented here.

Experimental

Excimer lamp

A planar lamp filled with 3.8×10⁴ Pa Kr and Br₂ mixture gas was made from a quartz tube of 30 mm diameter with a height of 7 mm. The lamp was driven by a 20 kHz sinusoidal power supply. The lamp voltage was 4 000 V and the amperage was 11.6 mA. An Acton VM-505 vacuum-ultraviolet monochromator was used in measuring the UV output. Figure 1 illustrates the UV emission spectrum from the KrBr* excimer lamp driven by DBD discharge. The peak of the emission from the KrBr* is observed around 207 nm. The full width half maximum (FWHM) of the 207 nm transition ($B_{1/2} \rightarrow X_{1/2}$) is approximately 2 nm. There is also weaker radiation at 222 nm ($C_{3/2} \rightarrow A_{3/2}$) and 228 nm ($B_{1/2} \rightarrow A_{1/2}$). The absolute radiance of the KrBr* UV source is obtained according to the following equation:

$$L_x = \int_{206}^{208} \frac{P_x(\lambda)}{P_D(\lambda)} \cdot L_D(\lambda) \cdot \left(\frac{D_D}{D_x}\right)^2 \cdot d\lambda \quad (1)$$

where:

L_x is the spectral radiance of the UV source (W m⁻² Sr)

$L_D(\lambda)$ is the spectral radiance of a pre-calibrated standard deuterium lamp (W m⁻² Sr)

$P_x(\lambda)$ and $P_D(\lambda)$ are respectively signals of the UV source and the deuterium lamp detected

D_D and D_x are respectively the diaphragm diameter of the UV source and the deuterium lamp.

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