脉冲电晕放电对印染废水脱色效果的实验研究*

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摘要 用高压毫微秒脉冲产生直接与废水接触的非平衡等离子体，能使印染废水在处理数10秒内脱除颜色。对模拟印染废水的实验研究表明：当脉冲峰值电压达38 kV时，脱色率不受试样pH值影响，在处理40 s后，脱色率达95%以上；当脉冲峰值电压较低时，脱色率与试样pH值有关，中性试样的脱色率较低，处理40 s后脱色率在40%—50%，而当pH<4或pH>7时，处理40 s后脱色率最高也可达80%以上。试样中加入NaCl和Na_2SO_4的实验结果表明：Cl^-使脱色率降低，而SO_4^{2-}使脱色率提高。

关键词 脉冲电晕，印染废水，脱色。

印染废水的脱色是印染废水处理的一个重要方面。现有的一些方法也能使印染废水有效脱色，但都存在一些问题。例如：吸附法难于适应染料的变化；电解法和臭氧法的投资大，运行费用高；辐射处理法的投资大等。为此，笔者提出了用高压毫微秒脉冲放电处理印染废水的方法，并对直接蓝2B和活性艳红X-3B染料水溶液进行了脱色试验，研究了溶液初始pH值、脉冲电压峰值、试样在放电室中处理时间和所加盐对脱色效果的影响。

1 高压脉冲放电处理印染废水的原理

根据文献[1, 2, 7]，当高能电子束轰击水溶液时，首先是水分子发生电离与激发，生成离子、激发分子与次级电子，这些辐射产物在向周围介质扩散前会相互作用，生成反应能力极强的物质[6]，在10^{-7} s内生成产物如下[1]：

$$H_2O \xrightarrow{\text{辐射}} \cdot OH[2.7] + e_{aq}^-[2.6] + \cdot H[0.6] + H_2O_2[0.7] + H_3O^+[2.6] + H_2[0.45] \quad (1)$$

高能电子束的发生通常是用加速器，但也可以利用高压毫微秒脉冲在常气压下产生。在陡脉冲电压作用下，电子在其自由行程内获得高能量，轰击水溶液，生成式(1)所列产物，与有机分子发生作用。另外，电子被加速到一定程度后，也会使氧气变成臭氧，臭氧溶于水后，同样会使有机物分解[3, 4]。电极间的电晕放电同时伴有紫外光的产生，这是由于气体分子激励状态的改变而产生的[8]。

综上所述，用高压毫微秒脉冲放电处理试样时有3种效应在起作用，即电子轰击、臭氧和紫外光。上述3种效应协同作用的结果可能比各效应单独作用有更好的处理效果。本文仅从脱色的角度进行研究。

2 实验装置和试品配制

实验装置包括高压毫微秒脉冲发生器、放电处理室、水泵、水容器和高压测量系统。图1为实验流程图。

高压毫微秒脉冲发生器产生的电压波形上升时间为20 ns左右。脉冲重复频率可调，本实验选用700 Hz。

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反应器电极采用线网-板电板结构，电极均采用不锈钢材料。

电压测量系统采用美国 Tek 公司产 P6105A 高压探头和100 MHz 示波器。

溶液的 pH 值使用雷磁 pHB-4型酸度计测定。

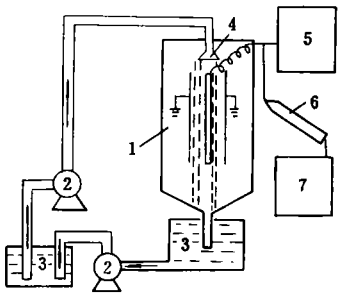

图1 实验流程

1. 放电处理室 2. 水泵 3. 水容器
4. 喷头 5. 高压脉冲发生器
6. 高压探头 7. 示波器

试样脱色效果的检验采用721型分光光度计，测量试样(处理或未处理)在可见光范围内的最大吸光度 A，并按下式计算其脱色率：

$$脱色率(\%)=\frac{A_0-A}{A_0}\times 100\%$$

式中 A_0为未处理试样的最大吸光度，A 为处理后的最大吸光度。

所用染料直接蓝2B 和活性艳红 X-3B 均由武汉市第四印染厂提供。模拟印染水浓度配制为200 mg/L。2种染料分子中，－N＝N－是发色团，－OH，$-NH_2$是助色团，$-SO_3Na$ 增加染料水溶性。

3 实验结果和讨论

3.1 脉冲电压峰值和溶液初始 pH 值的影响

图2、3、4所示为直接蓝试样在放电室中不同处理时间时，脱色率与溶液初始 pH 值之间的关系。由图中可看出，当所加脉冲峰值电压较低时(例如 U_m＝28 kV)，在溶液酸性较强情况下，脱色效果最好，处理40 s 后即可达到95%的脱色率；而在弱酸、中性和碱性溶液中，pH 值影响不显著，处理40 s 后，脱色率在40%—60%之间。这是因为当脉冲电压峰值较低时，电子被加速所获能量较少，于是轰击水溶液所产生的自由基较少。但此时电子能量已足以产生大量臭氧，在酸性介质中臭氧的标准氧化-还原电位(2.07 V)高于碱性介质(1.27 V)，其作用在酸性介质中较强。

在碱性介质中，臭氧被催化分解成·OH 基[3]，它能快速而无选择地与水中有机物反应，而不象在酸性介质中，臭氧主要破坏发色基团[4]。

当脉冲电压峰值增加时(例如 U_m＝33 kV)，

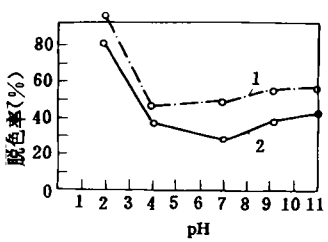

图2 直接蓝2B 在脉冲峰值 U_m＝28 kV 时，脱色率与 pH 值的关系

1. 处理40 s 2. 处理20 s

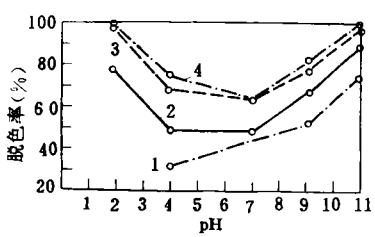

图3 直接蓝2B 在脉冲峰值 U_m＝33 kV 时，脱色率与 pH 值的关系

1. 处理20 s 2. 处理40 s
3. 处理80 s 4. 处理100 s

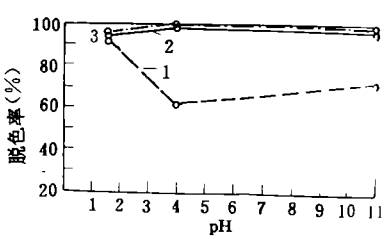

图4 直接蓝2B 在脉冲峰值 U_m＝38 kV 时，脱色率与 pH 值的关系

1. 处理20 s 2. 处理40 s
3. 处理60 s

在溶液初始 pH 值为强酸性和强碱性时，处理40 s 均能获得较高脱色率，处理80 s 后脱色率达95%以上。而此时，pH 值在中性周围的试样处理40 s 后，脱色率只接近50%，80 s 后在70%左右。对上述结果可解释如下：当脉冲峰值电压足够时，臭氧量和电子能量都大大增加，电子轰击中性溶液产生各种自由基的产率要低于酸性和碱性溶液，另一方面，此时放电室中已可看到

紫光产生，紫外光的作用在碱性介质中显著[5]。

当脉冲电压峰值进一步升高时，臭氧量、电子轰击和紫外光的作用都大大提高，由于它们的协同作用，使溶液初始 pH 值对脱色效果的影响不大。当试样处理时间超过40 s 后，不管初始 pH 为何值，脱色率均达95%以上。

对于活性艳红 X-3B，同样有上述结果，本文不再重复。

3.3　盐效应对脱色效果的影响

实际印染废水中往往含有一定量的无机盐，研究盐对脱色效果的影响是必要的。

图5、6、7所示为在试样中加入一定量的 NaCl或 Na_2SO_4后，脱色率与试样在放电室中处理时间的关系。可看出 NaCl 使脱色率降低，尤其在电压峰值低时，可使脱色率降低9.9%，而 Na_2SO_4使脱色率提高，最高可提高26%。这主要是因为 Cl^-的存在会降低染料的溶解度，增加染料分子的缔合度，从而影响了处理效果。而 SO_4^{2-}的存在，可以抑制 $-SO_4H$ 变成 $-SO_4^{2-}$，使染料分子保持良好的可溶性，从而使染料分子更容易与水中自由基反应。

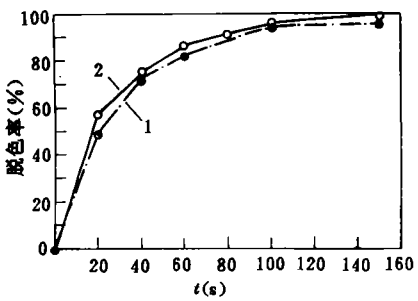

图5　活性艳红 X-3B 在 U_m=33 kV 时，Cl^-对脱色率的影响

pH=7.21　1. 加200 μg/g NaCl　2. 不加 NaCl

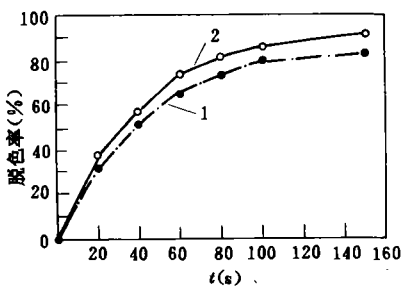

图6　活性艳红 X-3B 在 U_m=38 kV 时，Cl^-对脱色率的影响

pH=7.21　1. 加5000 μg/g NaCl　2. 不加 NaCl

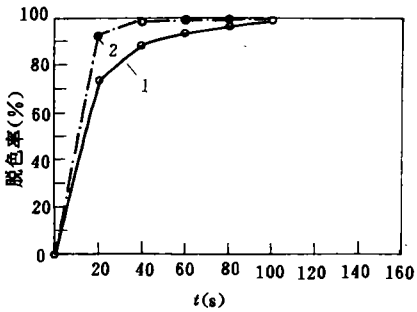

图7　直接蓝2B 在 U_m=33 kV 时，SO_4^{2-}对脱色率的影响，

pH=11.0　1. 不加 Na_2SO_4　2. 加1000 μg/g Na_2SO_4

4　结论

（1）用高压毫微秒脉冲放电处理印染废水能有效脱除颜色，脉冲峰值电压足够高时，40 s 内脱色率达95%以上，不受 pH 值影响。

（2）当脉冲峰值电压不高时，脱色率受溶液 pH 值影响较大，以酸性和碱性溶液脱色率较高，处理40 s 后，最高脱色率可达80%以上。

（3）印染废水中盐的存在对脱色效果有一定影响，Cl^-使脱色率降低，SO_4^{2-}使脱色率提高。

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A Study on the Biodegradation of Organic Substances by ATP Test. Sun Lixin et al. (Dept. of Environ. Eng., Tsinghua Univ., Beijing 100084): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 1—4

In this paper, the aerobic biodegradation of organic substances is characterized by the determination of the energy change, ATP content in microbial cells during the biodegradation. A satisfactory result was obtained under the following conditions: the initial concentration of the tested substance is 100 mg/L (as DOC), the amount of the inoculum in the biological medium is 500 mg/L (as MLSS), and the duration of test time is 14 days. The evaluating system (peak time, peak height index and IA index) is proposed to assess the biodegradability of 40 organic substances and 7 wastewater.

Key words: biodegradation, ATP, ATP test, IA index.

Effect of Salinity and Water Pressure on Adsorption of Toxic Organic Chemicals on Separated Submarine Sediment. Quan Xie et al. (Dalian Univ. of Technology, Dalian 116012): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 5—9

The organic and inorganic components of the submarine sediment from Dalian Bay were separated with a sequential chemical separation procedure. The adsorption of several toxic organic chemicals (TOCs) on the separated sediment samples and the effect of salinity and water pressure on the adsorptions were investigated. The conclusions were made as follows: (1) The adsorption capacity of organic components on the sediment increased as the salinity of water increased, but reduced for inorganic components. The relationships could be described with linear equations. (2) The adsorption capacity of both organic and inorganic components increased as the water pressure increased. The relationships could be described with exponential equations.

Key words: salinity, water pressure, submarine sediment, toxic organic chemicals.

The Influence of Diffusive Processes on Overlying Waters at the Sediment-water Interface of Lake Lugu. Wu Fengchang and Wan Guojiang (State Key Lab. of Environ. Geochem., Chinese Academy of Sciences, Guiyang 550002): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 10—12

Through the study on Ca^{2+}、K^+、Na^+、HCO_3^- and pH profiles of water column and porewater of Lake Lugu, Yunnan, a half-close and deep lake, it was found that Ca^{2+}、K^+、Na^+ and HCO_3^- in the sediments could diffuse to overlying water and their diffusive flux and their influence extent on overlying water could be quantitatively estimated. At also indicates that the interreactions between sediment and water play a significant role in controlling basic chemical composition of some lakes.

Key words: diffusive processes, sediment-water interface, Lake Lugu.

The Experimental Study on Decolorization of Dye Wastewater with Pulse Corona Discharge. Li Shengli et al. (Environment Center of Science and Technology, HUST 430074): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 13—15

A new method to decolor dye wastewater with pulse corona discharge has been developed. Nonequilibrium plasma produced by high voltage pulse discharge contacts with dye wastewater and decolorization of dye wastewater can be achieved quickly. The results showed that the decolorization rate can be reached more than 95% by treating wastewater for 40 s at pulse peak voltage of 38 kV and there is influence, of pH value on decolorization rate. When pulse peak voltage is lower, the influences of pH value on decolorization rate are appeared. The decolorization rate of neutral dye wastewater is only reached about 40%—50% after treating for 40 s. However, the decolorization rate can be reached more than 80% at pH<4 or >7. The experimental results of adding NaCl or Na_2SO_4 into dye wastewater have showed that Cl^- is able to decrease decolorization and SO_4^{2-} just opposite.

Key words: dye wastewater, decolorization, pulse corona discharge, pulse peak voltage.

Study on the Leaching Experiments of Minor and Trace Elements in Coal and Its Burnt Products. Wang Yunquan et al. (Beijing Graduate School, China Univer. of Mining and Technology, Beijing 100083): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 16—18

The comparative leaching experiments of coal (C), ashing ash (AA), fly ash (FA) and bottom ash (BA) have been carried out under different pH conditions. The leaching behaviour of As, Zn, Pb, Ni and Sr have been investigated in detail. The results have shown that the pH values of solution, leaching time, and particularly, the properties and species of the elements existed have heavily influenced on the leaching behaviour of elements. Among the 5 elements analysed, the leaching ability of Sr is strong, Pb and As strong to middle, Ni middle and Zn weak.

Key words: coal and its burnt products, minor and trace elements, leaching experiments.

A Study on Adsorption, Desorption and Biodegradation of Pentachlorophenol by Anaerobic Granular Sludge. Shen Dongsheng et al. (Dept. of Environ. Science, Zhejiang Agricultural Univ., Hangzhou, 310029): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 20—23

PCP degrading anaerobic sludge granules may be developed in upflow anaerobic digestion reactors (UAD) seeded with sludges acclimated to chlorophenols, the reactors are able to remove more than 99.5% of PCP in a synthetic wastewater at the concentration of 170 to 180 mg/L, volumetric loading rate up to 200 to 220 mg/(L·d), and hydraulic retention time of 20 to 22 hours. Biosorption and desorption isotherms of pentachlorophenol were determined, and the data were fitted to Freundlich equation. However, it was found that the biosorption of PCP was partly irreversible, and the Freundlich models with empirical constants determined from this study can quite well describe the partition behavior of pentachlorophenol in anaerobic upflow digestion reactor. It was demonstrated