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Removal of Phenol from Steel Industry Wastewater by using Electron Beam

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ABSTRACT

In this study, the degradation of phenol by electron beam irradiation in aqueous laboratory solutions as well as the wastewater of the steel industry has been investigated. The standard solutions of phenol in the range of 5-22 kGy underwent electron irradiation. Their concentrations before and after the exposure were measured using a UV-Vis spectrophotometer at 460 nm. The concentration of phenol in the effluent before and after irradiation at 10 kGy was measured by GC/MS analysis. The effect of experimental parameters like absorbed dose and initial concentration on the efficiency removal was studied. According to the observations, with increasing absorbed doses the removal percentage increases, and also in a constant dose by increasing the concentration the amount of removal gradually decreases. In the optimum dose, 10 kGy, the removal percentages of phenol in the standard solution with a concentration of 10 mg/L and in the wastewater of the steel industry were 93.5% and 41%, respectively.

Keywords: Electron Beam; Wastewater; Steel industry; Phenol

1. Introductions

Globally, water pollution is one of the most important environmental issues. Wastewater discharges from industrial and commercial sources may contain pollutants at levels that could affect receiving water. A nation's economic and technological growth is primarily driven by the iron and steel industry. However, this industry is associated with extensive environmental pollution and enormous water consumption. Different units of a steel plant discharge effluents loaded with toxic, hazardous pollutants, and unutilized components which necessitate moderation [1].

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Phenol discharged from steel industry effluents, in addition to discharge from chemical plants, pharmaceuticals, and petroleum refineries resulted in its wide existence in the environment [2]. Phenol is one of the oldest antiseptic agents and was used as disinfectant, chemical intermediate and mail cauterizer. Phenol is a general protoplasmic poison (denatured protein) with corrosive local effects. Absorbing phenol by inhalation, dermal application, and ingestion, results in systemic manifestations after a few minutes [3].

Various methods are used for the removal of phenol from wastewater [4]. Advanced oxidation processes (AOPs) are considered one of the most effective methods for the removal of phenol. AOPs are defined as the processes that generate hydroxyl radicals in sufficient quantity to be able to oxidize the majority of the industrial and complex chemicals present in the aqueous effluents [5]. Methods of (AOPs) for the treatment of phenol include ozonation [6, 7], Fenton reactions [8], photochemical [9], and compound oxidation process [10]. One of the AOPs is also radiation processing. Although the removal of all these methods is generally more than 90 %, irradiation is a green and fast method that generates more efficient strongly oxidizing hydroxyl radicals in aqueous solutions in comparison to other ones [11]. Electron beam (EB) irradiation is a promising technology for the removal of toxic organic compounds from the industrial effluents [11, 12]. EB technology destroys organic compounds in liquid wastes. When water is irradiated with high-energy electrons, it produces three reactive species, including aqueous electrons, hydrogen radicals, and hydroxyl radicals.

This paper presents phenol degradation in aqueous model solutions and wastewater samples by EB irradiation. The efficiency of the method was investigated by spectrophotometry using 4-amino antipyrine [13].

2. Materials and Methods

Chemicals and Reagents

All chemicals and reagents were of analytical grade (AR) or the highest purity available, obtained from Merck (Germany) and Panreac (Spain), and aqueous solutions were formulated in doubly distilled water. The stock solution of phenol was prepared by dissolving an appropriate amount in doubly distilled water. Experimental solutions of the desired concentrations were obtained by successive dilutions. Other materials used in this study include 4-amino antipyrine, potassium ferricyanide, chloroform, and ammonia. The steel industry wastewater was prepared from a steel plant in Iran.

Apparatus

Electron beam irradiation was performed with a Rhodotron TT200 accelerator (Belgium). A digitally calibrated pH meter from Mettler Toledo, model Seven Easy (Switzerland) was used to measure the pH. The analytical determination of phenol was carried out using a UV-Vis spectrophotometer Beckman colter, DU800 (USA). Gas chromatography-mass spectrometry (GC/MS) Aligent, model 7890A (USA) was employed to measure the concentration of phenol in wastewater before and after irradiation. Isolation was performed with a capillary type of poly dimethyl siloxane made of silica with a film thickness of 0.25 μm. Also, helium gas with 99.999% purity and 1 ml/min flow rate was used as a carrier gas. The injection type was divided with a

1 l volume, and the inlet temperature was 290 °C.

Sampling

Samples of wastewater from the steel industries were taken to the laboratory and stored away from light. The samples were filtered with filter paper to remove suspended materials before being treated. According to the steel plant data, the average annual presence of phenol in wastewater was 3-4 mg/l. Therefore, a phenol solution containing 10 mg/l was prepared.

Experimental method

Samples were irradiated with a 10 MeV electron beam accelerator. The irradiation was performed in plexiglass vessels with a dose range of 5-22 kGy. According to the 4-amino antipyrine method, sufficient ammonia was added to 10 mL of the phenol-containing sample to produce a final pH of 10±0.2. Then 0.5 mL of 4-amino antipyrine solution (1% w/v) and 2.5 mL of potassium ferricyanide solution (1% w/v) were added and the solution was thoroughly stirred. Extraction was performed with chloroform in 5 mL. The organic solution absorbance was measured at 460 nm by a spectrophotometer after extraction. The phenol removal efficiency was calculated by the following equation [13].

$$\%\text{Removal} = \frac{A_o - A_i}{A_o} \times 100$$

Where A_o and A_i are the absorbance of phenol solutions before and after treatment, respectively.

3. Results and Discussion

Effect of Radiation Dose

Aqueous solutions of phenol with 10 mg/L concentration were exposed to radiation at doses of 5, 10, 17, and 22 kGy. The relationship between degradation efficiency and absorbed dose was investigated. Figure 1 shows the effect of irradiation dose (5-22 kGy) on phenol degradation. For the aqueous solution of phenol, the removal percentage at 5 kGy dose is 72% and this amount increases with increasing dose (93.5, 96.55, and 98.27 % at 10, 17, and 22 kGy absorbed dose, respectively). As the removal percentage at 10 kGy is more than 90%, this dose is selected as optimal.

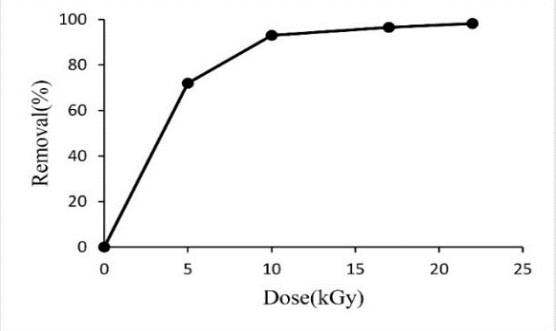

Fig. 1. Effect of radiation dose on the removal of phenol; (initial phenol concentration = 10 mg/L).

Effect of Initial Concentration

The initial concentration of phenol solution was varied from 1.5 to 10 mg/L (1.5, 3, 6, and 10 mg/L), and the samples were irradiated at 10 kGy. The percentage removal of phenol vs various concentrations has been shown in Figure 2. As seen, the highest percentage of removal, 98.3%, is obtained for 1.5 mg/L solution. The results show that in a constant dose with increasing the initial concentration from 1.5 to 10 mg/L, the removal percentage fairly decreases from 98.3 to 93.1%.

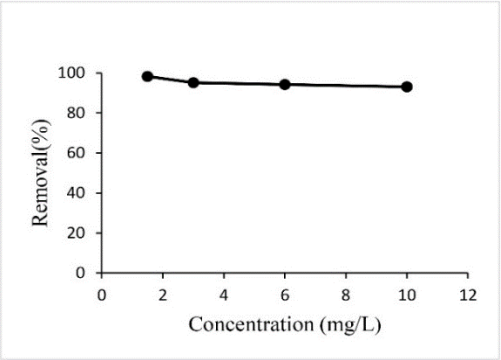

Fig. 2. Effect of initial phenol concentration on removal percent; radiation dose = 10 kGy.

Proposed Mechanism for Degradation of phenol

The proposed mechanism of phenol degradation due to electron beam irradiation is shown in Fig. 3. It seems that phenol is converted to oxalic acid and benzoic acid by a reaction with hydroxyl radicals induced by water radiolysis [14].

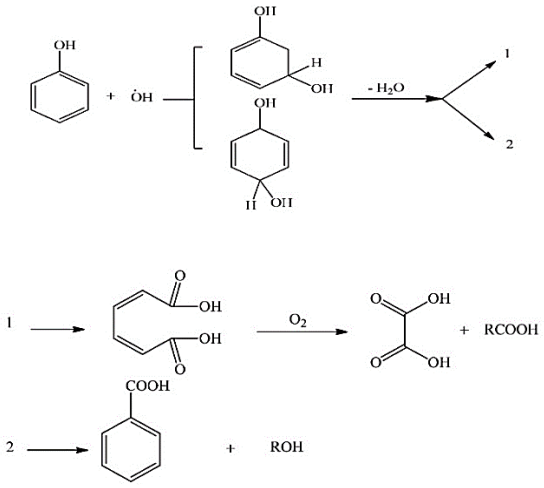

Fig. 3. Mechanism of phenol degradation under electron beam irradiation.

Treatment of Steel Industry Wastewater

First, the phenol sample was filtered with filter paper and spilled into plexiglass vessels. Afterward, irradiation was done at a 10 kGy dose. The results obtained by GC/MS showed that the removal percentage of phenol from this effluent was 41% (Fig. 4, and 5).

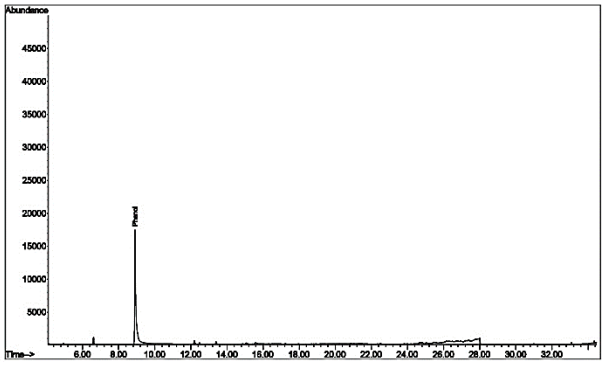

Fig. 4. GC/MS chromatogram of the effluent containing phenol before irradiation.

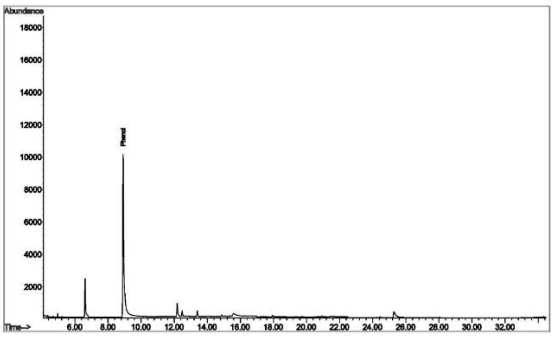

Fig. 5. GC/MS chromatogram of the effluent containing phenol after irradiation.

4. CONCLUSIONS

Based on the results, it can be concluded that phenol degradation by means of electron beam irradiation is a promising method with high performance. The results also show that the amount of initial concentration and irradiation dose is effective in the removal of phenol using an electron beam. Several advantages of this method are: (1) The process is a physical process and requires no additional chemicals, (2) This method does not damage the environment, and (3) The application of electron beam processing for wastewater treatment is a cost-effective process.

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