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An experimental investigation of wastewater treatment using electron beam irradiation

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HIGHLIGHTS

- Two pilot scale reactors are designed for EB irradiation of wastewater.
- The doses of 1 to 3 kGy are suitable for different wastewater.
- The synergism role of ozone treatment beside EB is investigated.
- The order of irradiation and coagulation is studied.
- Low doses of EB irradiation may result in BOD enhancement.

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ABSTRACT

Electron beam (EB) is used for disinfection and treatment of different types of sewage and industrial wastewater. However, high capital investment required and the abundant energy consumed by this process raise doubts about its cost-effectiveness. In this paper, different wastewaters, including two textile sewages and one municipal wastewater are experimentally studied under different irradiation strategies (i.e. batch, 60 l/min and 1000 m^3/day) in order to establish the reliability and the optimum conditions for the treatment process. According to the results, EB improves the efficiency of traditional wastewater treatment methods, but, for textile samples, coagulation before EB irradiation is recommended. The cost estimation of EB treatment compared to conventional methods shows that EB has been more expensive than chlorination and less expensive than activated sludge. Therefore, EB irradiation is advisable if and only if conventional methods of textile wastewater treatment are insufficient or chlorination of municipal wastewater is not allowed for health reasons. Nevertheless, among the advanced oxidation processes (AOP), EB irradiation process may be the most suitable one in industrial scale operations.

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1. Introduction

Treatment processes of wastewater are vastly investigated in the literature. These processes involve wastewater treatment in municipal, textile, pulp and paper, food, and a number of other industries. Wastewater treatment is important because of low potable water sources as well as health and environmental aspects. Alternative methods for wastewater treatment are simply classified into three major categories: primary (sedimentation and floatation), secondary (biological process), and tertiary or advanced treatment (Lin, 2007). Five agents have found common use in disinfecting drinking water. They include free chlorine, combined chlorine, ozone, chlorine dioxide, and ultraviolet irradiation (Davis, 2010). Some previous studies in the literature have reported economical evaluation of the conventional wastewater treatment methods (Fraas and Munley, 1984; Friedler and Pisanty, 2006; Hernandez-Sancho et al., 2011; Smith, 1968). Such applications as electromagnetic radiation, sound waves, and EB are categorized as nonconventional treatment methods (Cheremisinoff, 2001). The process of ozone formation in an oxygen-containing gas atmosphere by the action of ionizing radiation is well known (Gerasimov, 2004). Therefore, a process designer of EB treatment can use the produced ozone as well as irradiation for wastewater disinfection. Some authors have reported different processes and the profitability of application of high-power electron accelerators in wastewater treatment (Duarte et al., 2004; Emami-Meibodi

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et al., 2013; Gehringer, 2004; Gehringer and Fiedler, 1998; Han et al., 2009, 2005, 2012; Kim et al., 2006; Kurucz et al., 2002; Oh et al., 2014; Pikaev, 2000; Pikaev et al., 2001; Rela et al., 2000; Skowron et al., 2014).

To understand the details of the processes, highly sophisticated techniques are needed. The treated samples can be characterized by such standardized methods as the determination of chemical oxygen demand (COD), biological oxygen demand (BOD), total organic carbon content (TOC) and most probable number (MPN) index of the number of coliform bacteria. Currently, the accepted methods to determine color are ADMI tristimulus filter and UV absorbance methods. The degree of discoloration is usually calculated from the decrease of absorbance at a selected wavelength and, most conveniently, at the maximum absorbance (Abdou et al., 2011; Eaton et al., 1998; Kao et al., 2001; Neamtu et al., 2004; Ting, 2008; Vahdat et al., 2010; Wojnárovits and Takács, 2008).

As mentioned before, EB is used for discoloration of textile wastewater, disinfection of municipal wastewater, and COD or BOD reduction of wastewater containing organic species. In this research, disinfection of municipal wastewater is studied on a batch scale. In addition, textile wastewater samples from two factories are studied on a pilot scale.

2. Materials and methods

2.1. Raw samples

Two samples of Yazd-Baf Co. wastewater and one sample of Naghshin Co. wastewater were used for the pilot plant scale. Hach DR5000 was used for COD measurements, and BOD was measured based on the standard titration method. The turbidity and conductivity were measured using a Hach 2100AN turbidimeter and a WTW-LF90 conductivity meter respectively. In addition, the samples of municipal wastewater were used for a disinfection test after the biological treatment conducted by Yazd wastewater treatment plant (i.e. before chlorination). The COD, BOD, turbidity and coliforms of the raw and irradiated municipal samples were measured by Azma Ilia Sanat Isatis laboratory according to the standard methods. The raw samples data are shown in Table 1.

2.2. Experimental set-up

In this study, a 10 MeV electron beam of a Rhodotron TT200 accelerator in Central Iran Research Complex (CIRC) was used for the irradiation step.

The pilot scale reactors were designed with wastewater flow rates of 60 l/min and 1000 m^3/day. A rectangular cubic AISI 316 Stainless Steel with 1404 × 78 × 75 mm dimensions was selected as the reactor with the flow rate of 60 l/min (Reactor-1). The upper side of this reactor was a 30-micron titanium foil tightened by two frames and some screws. Two baffles with the height of 4 cm were embedded in the reactor at 10 cm from its entrance and exit. A tube with the inner diameter of 5 mm was used at the entrance of the reactor for an ozonation process. A ceramic rectangular diffuser was also used to purge the ozone in the wastewater. Fig. 1 shows the schematic plot of Reactor-1. The height of the reactor (75 mm) was selected based on the previous tests. Of reactors of various heights (28, 75, 100 and 150 mm), it proved to have the best efficiency. For the flow rate of 1000 m^3/day, a rectangular cubic AISI 316 Stainless Steel with 1200 × 90 × 150 mm dimensions was used (Reactor-2). A titanium foil was applied at the upper side of the reactor in the front of EB window. However, five plates with the dimensions 1200 × 115 mm were installed as turbulators. In addition, wastewater entrance and exit ducts with two right triangular prisms were mounted lengthwise on the reactor as shown in Fig. 2. The entrance pipe of the wastewater was placed on the upper side of the duct in order to smoothly fill the whole reactor.

Table 1
The properties of raw samples from Yazd-baf Co., Naghshin Co. and Yazd wastewater treatment plant.

Sample	pH	COD [mg/l]	BOD_5 [mg/l]	Turbidity (NTU)
Yazd-baf-1	11.18	1274	–	–
Yazd-baf-2	12.3	632	311	75
Naghshin	7.7	982	490	77
Yazd municipal	–	105.5	66.43	1.4

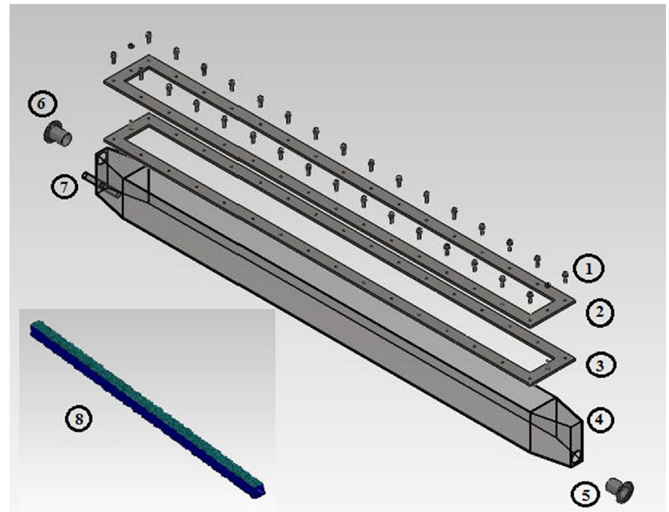

Fig. 1. Schematic plot of Reactor-1 (60 l/min). 1: screws; 2: upper frame; 3: lower frame; 4: reactor; 5: wastewater entrance; 6: wastewater exit; 7: ozone entrance; 8: ozone diffuser.

In this research, 2 m^3 of the Yazd-baf-1 sample was used for EB irradiation with and without ozonation. The wastewater flow-rate and the accelerator current were 50 l/min (by Reactor-1) and 2 mA, respectively. Ozone was generated by an industrial ozone generator purchased from Ozoneab Co., Ltd., Iran. The rate of ozone generation was 0.1 g/min, $T=300$ K and $P=1.2$ bar. In addition, 1.5 m^3 of Yazd-baf-2 sample was treated by coagulation and irradiation processes. The chemical coagulation step was

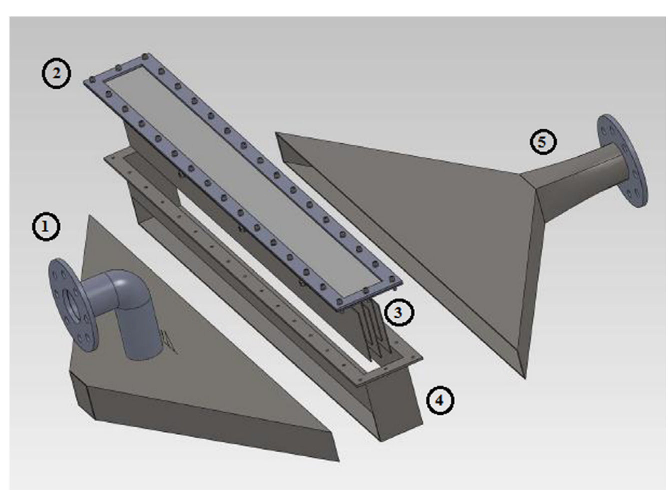

Fig. 2. Schematic plot of Reactor-2 (1000 m^3/day). 1: wastewater entrance; 2: foil-frames ensemble; 3: turbulators; 4: reactor; 5: wastewater exit.

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