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O_3/UV photo-oxidation for the removal of reactive yellow 3 dye from wastewater

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ABSTRACT

Chemical colors used in the textile industry are potentially risky because they are carcinogenesis and mutagenesis to humans. The current study purposed to remove reactive yellow 3 dye from wastewater using the advanced oxidation process of O_3/UV. Tests were performed under optimum conditions (pH = 9, contact time = 40 min, ozone concentration = 0.9 g/h, and an initial concentration of 10 mg/L reactive yellow 3 dye) on real samples. The maximum efficiency rates of removal of reactive yellow 3 dye under optimum conditions for soluble synthetic and real samples of wastewater from the Yazdbaf textile factories using the O_3/UV photo-oxidation process were 96% and 85%, respectively.

Keywords: Advanced oxidation; Reactive yellow 3 dye; Ozone; Photo-oxidation of O_3/UV

1. Introduction

Millions of liters of colored effluent are produced by textile industries and factories. Each milliliter of this wastewater can contain no more than 20 g of pigments or interfaces that result from its degradation, thereby causing environmental problems. The chemical colors used in these industries in the process of manufacturing poses potential risks of carcinogenesis and mutagenesis to humans. In addition, different colors influence colored surface and underground waters used as water sources [1].

Various methods such as electro-coagulation absorption, the Fenton process, and removal of color combinations have been applied [2]. Advanced oxidation processes such as ozone, UV radiation, optical breakdown by oxidation of hydrogen peroxide, and Fenton oxidation are effective for the removal of organic contaminants in water and wastewater. Hydroxyl free radical processes during oxidation with potential 2.7 V production is the main factor for the removal of contaminants.

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Advanced oxidation processes can be used as a single or a combined process [3]. Advanced oxidation processes based on the production of hydroxyl free radicals that focus on H_2O_2, O_3 or operate as air oxidizing and UV waves of energy are used as external hydroxyl free radicals with the capability of high oxidation, causing the degradation of contaminants and their removal from water and wastewater [4]. These processes include the use of strong oxidant agents for organic pollutant degradation in the presence or absence of a source of radiation. The main advantage of the advanced oxidation method is that it prevents the production of secondary pollutants; further benefits include its high speed and productivity [5].

Ozone (O_3) is a strong oxidizing agent. A lot of research has shown that the use of UV light increases the power of the oxidation process. UV can be combined with O_3 and optimum conditions for the production of hydroxyl free radicals and to provide a more complete analysis of the pollutant [3,4].

Zhaoqian et al. [3] conducted a study in China on the oxidation of UV/O_3 in combination with an aerobic biological filter using an advanced oxidation technique. The removal of the top organic contaminants at a low cost resulted in the

removal of more than 61% chemical oxygen demand (COD) from wastewater. The analysis of COD and total organic carbon is important in wastewater removal. In Finland, Lucas et al. [6] examined the performance of advanced oxidation processes based on O_3/UV and UV/O_3/H_2O_2 for a wastewater treatment plant used for the production of alcoholic beverages. They showed that the efficiency of sewage removal is pH-dependent. In Iran, Mostafaii et al. [7] compared two methods of advanced oxidation of UV/O_3/H_2O_2 and O_3/UV in urban waste leachate treatments. They showed that the O_3/UV method was more effective than the UV/H_2O_2/UV method. Excellent removal rates of biological oxygen demand, COD, and color were seen. The O_3/UV method was able to increase the biological degradability of leachate. Malakootian et al. [8,9] have researched the removal of color from aqueous solutions using different methods.

To date, the removal of reactive yellow 3 acidic dye by photo-oxidation of O_3/UV has not been researched. The current study evaluated the performance of this method in removing reactive yellow 3 from synthetic and real samples of water solutions in vitro from the Yazdbaf sewage textile factory.

2. Experiments

2.1. Materials and methods

Experiments were done in the Environmental Health Engineering Research Center of Kerman University of Medical Sciences on sewage from the textile factory and the kinetics of soluble compounds from Yazdbaf on a laboratory scale and in a batch system. The pilot initially required plexiglass and a cylinder with the height of 45 cm, interior diameter of 7 cm, and useful volume of 1 L was built, as shown in Fig. 1.

The more soluble reactive yellow 3 dye with a concentration of 1,000 mg/L was the final soluble sample used. Then, concentrations of 25, 20, 15, and 10 mg/L were each added to 250 mL with the dilution solution. The pH values of the soluble samples (5, 7, and 9) were adjusted by adding sodium hydroxide and sulfuric acid of 0.1 N. To evaluate the impact of ozone dose on the removal of reactive yellow dye in the O_3/UV photo-oxidation process, doses of 0.5, 0.7, and 0.9 g/h were considered.

Samples were taken at intervals of 40, 30, 20, and 10 min for the reactors. Then, the amount of UV–Vis absorption was measured using spectrophotometry and the concentration of the remaining reactive yellow 3 dye in the sample was obtained using the best fit line from the standard curve.

Finally, after determining the physical and chemical qualities of the sewage, the rate of light absorption under optimum conditions from textile industry sewage was evaluated. To increase the coefficient of reliability and accuracy, the experiment was repeated three times and the results were reported as the average.

All samplings and experiments were conducted in accordance with the procedures set in the *Water and Wastewater*, 18th edition. UV radiation using a 15 W bulb of UV light (Philips, the Netherlands; made of a quartz inside casing with vaginalis in the center of the reactor which was installed). Ozone gas was embedded in the floor of the entrance of the pilot. For the production of ozone from the ozone generators (MOG; Ardai of France) with a nominal capacity of 5 g/h, the input gas was produced using air compressors. The dose of ozone in the airflow was measured using the method of absorption of potassium iodide (iodometry). Airflow was used for the production of ozone. To provide air, an air pump (Dubai) was regulated with the help of a degree and a rotameter. The pH was adjusted using a pH meter. Reactive yellow 3 dyes and other chemicals used in this research were products of Merck, Germany. Results obtained were statistically analyzed using SPSS 16 software.

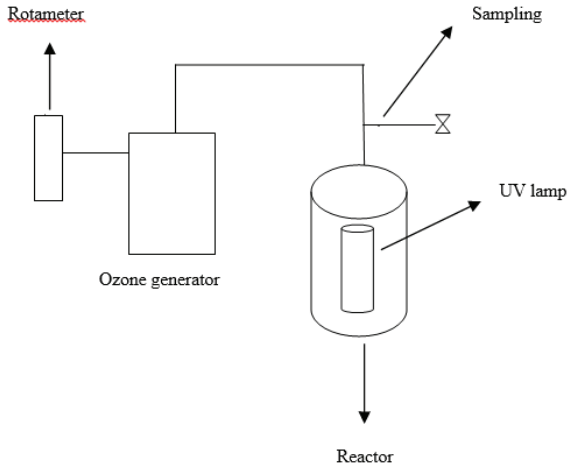

Fig. 1. Pilot components used in the process of O_3/UV photo-oxidation.

3. Results and discussion

3.1. Effects of pH

The results of the influence of pH on the process of O_3/UV photo-oxidation with a concentration of 10 mg/L reactive yellow 3 dye at pH of 5, 7, and 9 are shown in Fig. 2.

According to the results shown in Fig. 2, alkaline pH due to the decomposition of ozone and the removal efficiency is higher and pH 9 is the optimum pH.

The results indicated that the maximum amount of reactive yellow 3 dye removed in the process of O_3/UV photo-oxidation was obtained in alkaline pH. Decomposition of O_3 in water is absolutely dependent on pH, and its

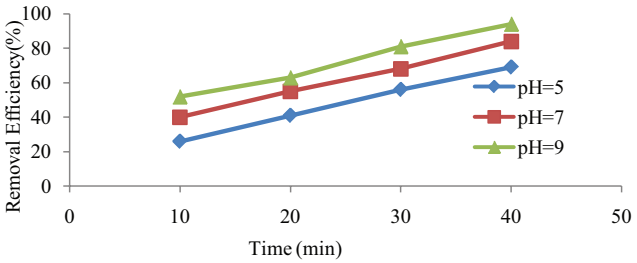

Fig. 2. The impact of pH on removal of reactive yellow 3 dye with concentration of 10 mg/L, ozone dose of 0.9 g/L and contact time of 40 min during the process of O_3/UV photo-oxidation.

decomposition is accelerated by high pH. Under alkaline conditions, O_3, by increasing OH^- ions, will more easily convert to hydroxyl radical ($OH^•$), which is a strong oxidant (Reactions 1 and 2). In Taiwan, Yang et al. [10] concluded that the removal of nitrobenzene by ozone was very low at pH 2, whereas by increasing pH, the rate of nitrobenzene removal increased as well, which corresponds with the results of the current research.

$$O_3 + OH^- \rightarrow O_2^• + HO_2^• \quad (1)$$

$$O_3 + HO_2^• \rightarrow 2O_2 + HO^• \quad (2)$$

3.2. Effects of ozone dose

The results of the impact of ozone dose (0.5–0.9 g/h) on the removal of reactive yellow 3 dye in the process of O_3/UV photo-oxidation is shown in Fig. 3.

According to the results shown in Fig. 3, with each increase in ozone dose from 0.5 to 0.9 g/h, the amount of reactive yellow 3 dye removal also increased. The maximum removal efficiency obtained was 94% in an ozone dose of 0.9 g/h.

The findings of the current study showed that with an increase in O_3 dose, the O_3/UV photo-oxidation process in the removal of reactive yellow 3 dye was increased. O_3 is a strong oxidizing substance that can directly decompose polluting molecules (Reaction 3). The attack of the O_3 water molecules cause decomposition and the production of hydroxyl free radicals (OH) and hydrogen peroxide (H_2O_2), which are both products of strong oxidizing agents in the decomposition of polluting molecules (Reactions 3–5) [4,2].

$$O_3 + \text{dye} \rightarrow CO_2 + H_2O \quad (3)$$

$$O_3 + H_2O \rightarrow 2OH^• \quad (4)$$

$$O_3 + H_2O \rightarrow H_2O_2 + O_2 \quad (5)$$

In Iran, Rashidi et al. [11] investigated the effects of relative humidity, ozone dose, and reaction time on the efficiency of the process of O_3/UV analysis of airflow performed with benzene. Their results showed that when there is an increase in the dose of ozone, there are increased benzene efficiency indicators; this result corresponds to that of the present investigation.

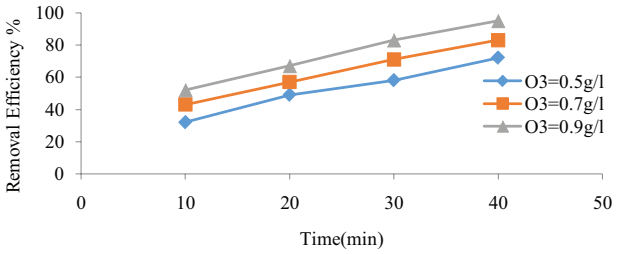

Fig. 3. The impact of ozone dose on the removal of reactive yellow 3 dye with concentration of 10 mg/L, pH 9 and contact time of 40 min in the process of O_3/UV photo-oxidation.

3.3. Effects of reactive yellow 3 dye concentration

The results obtained for the impact of dye concentration on the removal of reactive yellow 3 dye in the process of photo-oxidation of O_3/UV are shown in Fig. 4.

According to the results, any increase in concentration had a negative impact on the removal of reactive yellow 3 dye. The maximum removal efficiency was 95% with a concentration of 10 mg/L reactive yellow 3 dye.

In the present study, increases in the concentration of reactive yellow 3 dye resulted in decreases in removal efficiency in the process of photo-oxidation of O_3/UV. The greater the dye concentration of the substance was, the darker the color of the dye solution would be. Furthermore, the amount of UV light (low) that needed to pass through for removal efficiency was reduced because of the reduced production of hydroxyl radicals (OH). In Iran, Rezaee et al. [12] compared two methods of removing reactive 71 dye: advanced oxidation, photochemical and sonochemical methods studied in combination with hydrogen peroxide. Their results showed that the amount of dye removed with the advanced oxidation system decreased with each increase in initial dye concentration; this result corresponds with the results of the present study. The current results indicated that UV photolysis greatly improved reactive yellow 3 dye removal during ozonation. In China, Zhaoqian et al. [3] studied the oxidation of UV/O_3 in combination with an aerobic biological filter. It was feasible to combine UV/O_3 oxidation with BAF to improve COD removal in tertiary wastewater treatment.

3.4. Effects of different contact time

The results of different contact times on the removal of reactive yellow 3 dye in the process of O_3/UV photo-oxidation is shown in Fig. 5.

As shown in Fig. 5, with each increase in contact time in the process of photo-oxidation of O_3/UV, the amount of reactive yellow 3 dye removal increased. After 40 min in the present study, there was no dramatic difference in the removal efficiency in different concentrations; thus, this time for photo-oxidation of O_3/UV process was optimal.

The results regarding the effects of reaction time on the amount of reactive yellow 3 dye removed showed that, whatever the duration of a long response is, there is more reactive

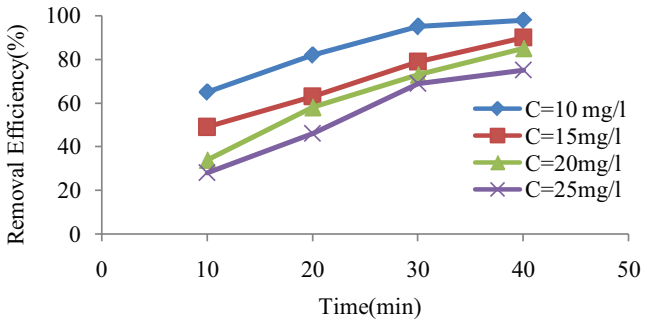

Fig. 4. The impact of different concentrations of reactive yellow 3 on the removal of reactive yellow 3 dye with pH 9, ozone dose 0.9 g/h and contact time of 40 min in the O_3/UV photo-oxidation process.

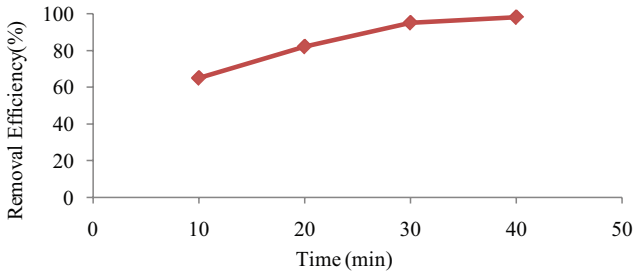

Fig. 5. The impact of different contact time on the removal of reactive yellow 3 dye in the photo-oxidation of O_3/UV process with dye concentration of 10 mg/L, pH 9 and ozone dose of 0.9 g/h.

yellow 3 dye removal for a sample exposed to the O_3/UV oxidation process, and a high percentage of removal can be achieved. In a study conducted by Rashid et al. [11] in Iran, the effect of relative humidity, ozone dose, and reaction time on the efficiency of the process of O_3/UV analysis of the airflow for benzene was shown. The results showed an increase in reaction time, and an increase in efficiency analysis was found for benzene, which corresponds with the results of the present investigation.

3.5. Comparison of the UV photolysis, ozonation, and UV/O_3 oxidation

Fig. 6 shows reactive yellow 3 dye variation in the oxidation reactor with time under UV photolysis, ozonation, and UV/O_3 oxidation.

It can be seen that the amount of reactive yellow 3 dye removed with UV photolysis alone was low. With 40 min of contact time, the maximum removal efficiency was 61%. Ozonation performed much better compared with UV photolysis. After 40 min of ozonation, removal efficiency was 74%. The combination of UV photolysis and ozonation led to a significant improvement in reactive yellow 3 dye removal compared with UV photolysis and ozonation alone. With 40 min of contact time, the reactive yellow 3 dye removal efficiency was 94%, which was much higher than the sum of the reactive yellow 3 dye removal efficiency rates with UV photolysis and ozonation alone.

3.6. Real samples of Yazdbaf textile factory wastewater

The physical and chemical properties of the real samples (wastewater from the Yazdbaf textile factory) are shown in Table 1.

The optimum rate of removal of reactive yellow 3 dye from real samples was 85%, which is less than the removal efficiency from the synthetic samples.

The interference of pollutant present in real wastewater samples, such as dissolved organic matter, suspended organic matter, sulfate anion, phosphate anion, and other soluble chemical compound led to a reduction in the efficiency of the O_3/UV oxidation process. The presence of these compounds thereby confounded with reactive yellow 3 dye removal efficiency of 96% in solution as compared to 85% in real wastewater samples.

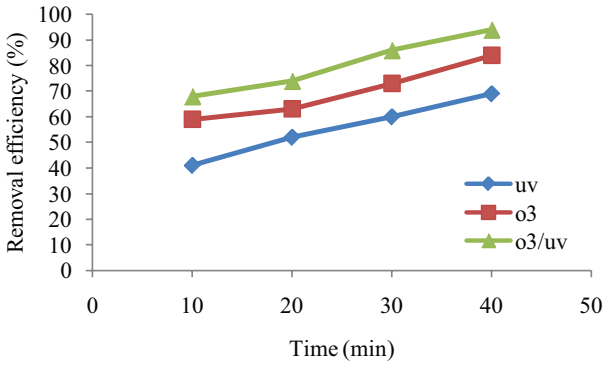

Fig. 6. Reactive yellow 3 dye changes with time under UV photolysis, ozonation and UV/O_3 oxidation (O_3 dosage 0.9 mg/L, pH 9).

Table 1
Physical–chemical characteristics of the waste water of textile factory in Yazd BAF

Parameters	Amount
Benzene (mg/L)	152
Opacity (NTU)	640
Detergent (mg/L)	120
Ni (mg/L)	16
Pb (mg/L)	30
Cr (mg/L)	20
EC (μs/cm)	4,840
BOD (mg/L)	280–320
pH	11
TSS (mg/L)	2,200
TDS (mg/L)	9,300–10,700
COD (mg/L)	662–3,280

EC, electrical conductivity; BOD, biochemical oxygen demand; TSS, total suspended solids; TDS, total dissolved solids; COD, chemical oxygen demand.

4. Conclusion

The O_3/UV photo-oxidation process is highly efficient in removing reactive yellow 3 dye from water solutions with an efficiency rate of 85% removal from real wastewater samples. Oxidation speed depends on many factors, including ozone dose, pH, reaction time, and pollutant concentration. Due to the benefits of this method, such as no by-products harmful to human health or the environment, its high-efficiency as compared with methods such as adsorption, and its innovativeness, it is advisable to use O_3/UV photo-oxidation in treating wastewater from the textile industry.

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