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Solar driven decolourisation of Reactive Yellow 14 by advanced oxidation processes in heterogeneous and homogeneous media

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Abstract

This paper evaluates the decolourisation of an azo dye Reactive Yellow 14 (RY14) by three advanced oxidation processes viz., solar/TiO_2, solar/H_2O_2 and solar/H_2O_2/Fe^{2+} (photo-Fenton). The results showed that all the three processes could be effectively used for the decolourisation. The study on the effects of various experimental parameters such as pH, dye concentration, light intensity on the solar decolourisation revealed that these parameters influenced the removal rate. The photodecolourisation efficiencies with solar irradiation are comparable to UV irradiation. It is found that these three solar processes are viable techniques for the decolourisation of RY14.

Keywords: Reactive Yellow 14; Advanced oxidation processes; Solar light; Decolourisation

1. Introduction

Industrial wastewater contains rich source of non-biodegradable contaminants [1]. In recent years advanced oxidation processes (AOPs) are effectively used to detoxify noxious and recalcitrant pollutants in industrial wastewater. The potentialities offered by AOPs can be utilized to integrate the biological treatments by an oxidative degradation of toxic or refractory substances entering or leaving the biological stage. AOPs generate powerful reactive species hydroxyl radical (·OH). These ·OH radicals attack rapidly and non-selectively the most organic molecules. The versatility of AOPs is also enhanced by the fact that they offer different possible ways for hydroxyl radical production and thus allowing a better compliance with the specific treatment requirements.

The advanced oxidation processes can make use of solar energy instead of artificial light sources. The artificial light sources need high electrical power, which is costly and hazardous. Furthermore, solar energy is an abundant natural energy source in tropical countries like India.

Among the advanced oxidation processes the homogeneous AOPs employing H_2O_2 [2–5] and H_2O_2/Fe^{2+} [6,7] and heterogeneous AOPs employing semiconductor materials as photocatalysts [8–12] have been found to be very effective in the degradation of pollutants. The reactive azo dyes are most important class of synthetic organic dyes used in the textile industries and are therefore common industrial pollutants. These dyes are found to be non-biodegradable.

In the present work we report the photodegradation of a reactive class mono azo dye Reactive Yellow 14 (RY14) by three AOPs using TiO_2, H_2O_2 and H_2O_2/Fe^{2+} with solar light. We have analysed the influence of various parameters on photodecolourisation to find out the optimum conditions for efficient colour removal.

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The structure and absorption maximum of Reactive Yellow 14 are shown in Table 1.

2. Experimental

2.1. Materials

The commercial azo dye Reactive Yellow 14 obtained from Colour Chem Pondicherry was used as such. A gift sample of TiO_2-P25 was obtained from Degussa (Germany). It has the particle size of 30 nm and BET specific surface area of 50 m^2/g. AnalaR grade reagents H_2O_2 (30% w/w) and $FeSO_4 \cdot 7H_2O$ (Merck) were used as received. The double distilled water was used to prepare experimental solutions. The natural pH of the aqueous dye solution is 5.5. The experimental solutions were adjusted to the decided pH by the addition of H_2SO_4 or NaOH.

2.2. Irradiation experiments

All photocatalytic and photochemical experiments were carried out under similar conditions on sunny days of 2002–2003 between 11 AM and 2 PM. An open borosilicate glass tube of 50 ml capacity 40 cm height and 20 mm diameter was used as the reaction vessel. The suspension was magnetically stirred in the dark for 30 min to attain adsorption–desorption equilibrium between dye and TiO_2. Irradiation was carried out in the open-air condition. Fifty milliliters of dye solution with TiO_2 was continuously aerated by a pump to provide oxygen and for the complete mixing of reaction solution. During the illumination time no volatility of the solvent was observed.

2.3. Procedure

At specific time intervals 2 ml of the sample was withdrawn and centrifuged to separate the catalyst. One milliliter of the centrifugate was diluted to 10 ml and its absorbance at 410 nm was measured. The absorbance at 410 nm ($n \rightarrow \pi^*$ transition of $-N{=}N-$ group) is due to the colour of the dye solution and it was used to monitor the decolourisation. For solar/H_2O_2 process a desired molar ratio of dye/H_2O_2 at pH 3 was freshly prepared before the experiments. For photo-Fenton process a desired molar ratio of dye/Fe^{2+}/H_2O_2 solution was freshly prepared from $FeSO_4 \cdot 7H_2O$ and the dye stock solution. The pH of the solutions was adjusted to 3.0 for solar/H_2O_2 and photo-Fenton processes. After irradiation the absorbance was measured immediately to avoid further reaction. The pH of the solutions after irradiation was adjusted to 5.5 before taking the concentration measurements.

2.4. Solar light intensity measurements

Solar light intensity was measured for every 30 min and the average light intensity over the duration of each experiment was calculated. The sensor was always set in the position of maximum intensity. The intensity of solar light was measured using LT Lutron LX-10/A Digital Lux meter. The solar intensity was 1100 × 100 Lux and it was nearly constant during the experiments. UV spectral analysis was done using Hitachi U-2001 spectrophotometer. The pH of the solution was measured by using HANNA phep (model H 198107) digital pH meter.

3. Results and discussion

3.1. Solar/H_2O_2 process

The photodecolourisation of RY14 under different conditions is shown in Fig. 1. The dye does not decolourise on irradiation in the absence of H_2O_2. The dye solution with H_2O_2 in dark undergoes 12.7% decolourisation in 120 min. At the same time, irradiation with solar light and H_2O_2 gives 71.2% decolourisation. The decolourisation of dye is due to oxidation by hydroxyl radical (Eqs. (2) and (3)) formed in the solution

Table 1
The characteristic of Reactive Yellow 14 dye

Azo dye	Formula	Abs	M_w
Reactive Yellow 14	$C_{20}H_{19}N_4O_{11}S_3Na_2Cl$	410,254 nm	669.0

Chemical Structure