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Degradation of toxic azo dye (AO7) using Fenton's process

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Abstract. This study aimed at advanced oxidation of hetero tri-functional reactive dye Acid orange 7 using photo-Fenton conditions in a lab-scale experiment. Decolourisation of Acid Orange 7 dye by Fenton's process was dependent on concentration of Hydrogen peroxide, Ferrous sulphate, pH, and contact time. A 2^3 factorial design was used to evaluate the effects of these key factors: pH, Fe(II), and H_2O_2 concentration, for a dye concentration of 50 mg/L with COD of 340 mg/L at pH 3.0. The response function was removal of colour under optimised conditions; pH 3.0, [Fe(II)] 40.83 mg/L, [H_2O_2] 4.97 mmol/L; 13.6 min. of treatment resulting in 100% colour removal. The final COD of treated wastewater was nil suggesting that AOP is a potentially useful process of color removal and dye degradation/mineralisation of effluent having AO7. Minimum contact time for complete decolourisation was at 5 mmol/l H_2O_2 concentration. Increase in $FeSO_4$ (mg/l) concentration resulted in decrease of time for complete decolourisation. Box-Behnken Design was used to optimize the process variables. Maximum and minimum levels of pH (3-5), H_2O_2 (4-6 mmol/l), $FeSO_4$ (30-46 mg/l) and contact time (5-15 minutes) were used. The statistical analysis revealed a value of 0.88 for coefficient of regression (R^2) indicating a good fit of model. Calculated F-value was found higher than the tabulated value confirming to significance of the model. Based on student's t-test, Ferrous sulphate, pH, and contact time have a positive effect on the percent decolourisation of Acid Orange 7.

Keywords: Acid Orange 7; Fenton's process; decolourisation; Box-Behnken design; textile dye

1. Introduction

Synthetic textile dyes are one the most consumed chemicals with more than 10,000 different dyes being used in industries all over world (Hsueh *et al*. 2005, Ganesan and Thanasekaran 2011). Azo dyes constitute about 50% fractions of total dyes being used (Neamtu *et al*. 2002, Sun *et al*. 2009). In India, about 200.54 MT of dyes and pigments were produced during the year 2013-14 (DCPC 2014). Wastewater generated from dye manufacturing and processing units is found to contain about 10 to 15% fraction of the dyes produced having high colour intensity (Pierce 1994, Reife and Freeman 1996, Peternel *et al*. 2007, Sun *et al*. 2007). Discharge of dye containing wastewater in water bodies interferes with sunlight penetration thereby reducing rate of photosynthesis and adversely affecting aquatic flora and fauna (Chung and Stevens 1993, Meric *et al*. 2004). The intermediate products of dyes and pigments are chemically similar to aromatic hydrocarbons and are toxic, mutagenic, and carcinogenic (Haritash and Kaushik 2009). Several

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studies on toxicity assessment of dyes have concluded that most of the textile dyes are toxic to phytoplanktons and zooplanktons even at very low dosages (Liu *et al*. 2007, Ferraz *et al*. 2011, de-Luna *et al*. 2014).

Conventional treatment methods like Activated Sludge process, adsorption onto activated carbon, coagulation by a chemical agent, hypochlorite oxidation, electrochemical method etc. were found to be either ineffective, or energy-intensive costly chemical methods seldom achieving complete decolourisation/degradation (Yoshida *et al*. 1999, Tanaka *et al*. 2000, Shen *et al*. 2001, Sun *et al*. 2007). Destructive treatment technologies like Advanced (chemical) oxidation processes (AOPs) reporting reduction/elimination of toxicity, and mineralisation of organic pollutants are promising tools for remediation of organic pollution (Rodrigues *et al*. 2009). Hence, AOPs are becoming popular in recent years for treatment of textile-industry wastewater. Different AOPs like photocatalysis (Sharma *et al*. 2015), ultrasonication, ozonation generate hydroxyl radicals ($^\bullet OH$) facilitating dye degradation, but the mechanism by which $^\bullet OH$ radicals are generated is different for each process.

During Fenton's process $^\bullet OH$ radicals are generated by reaction between hydrogen peroxide and ferrous ions (Fe^{2+}). $^\bullet OH$ radicals are very strong oxidising agents with ORP value of 2800 mV second only to fluorine. Following reactions describe the Fenton's oxidation process:

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + {}^\bullet OH + OH^- \quad (1)$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + {}^\bullet OOH + H^+ \quad (2)$$

$$Fe^{3+} + {}^\bullet OOH \rightarrow Fe^{2+} + H^+ + O_2 \quad (3)$$

$$^\bullet OH + H_2O_2 \rightarrow {}^\bullet OOH + H_2O \quad (4)$$

$$^\bullet OH + Fe^{2+} \rightarrow Fe^{3+} + OH^- \quad (5)$$

$$^\bullet OH + {}^\bullet OH \rightarrow H_2O_2 \quad (6)$$

$$^\bullet OH + {}^\bullet OOH \rightarrow O_2 + H_2O \quad (7)$$

Fenton's process is divided into two stages. First stage involves oxidation of Fe^{2+} during first few minutes; the second stage involves regeneration of ferrous ions and reaction rate is slow compared to that of the first stage. $^\bullet OH$ radicals attack the dye molecule by hydroxylation and epoxidation of aromatic rings, cleaving of azo bond, and desulfonation (Bansal *et al*. 2010, Meetani *et al*. 2010).

The variable parameters in Fenton's process are concentration of H_2O_2, $FeSO_4$, pH, contact time etc., and the optimization of these variables can be done using univariate and multivariate approach. It is very cumbersome and time consuming to vary one parameter while keeping other parameters constant i.e., using univariate approach. This method doesn't allow for the study of interactions between different parameters. Multivariate approach reduces the number of experiments and time to study the interactions between different variables. Response Surface Methodology (RSM) is a reliable and time efficient tool for optimization of multivariate experiments as it uses minimum set of designed experiments to obtain an optimal response using statistical techniques (Francis *et al*. 2003). RSM uses lower order polynomial which is the fit of empirical models to the experimental data obtained in relation to experimental design. Central Composite Design, Three - level factorial design, Box - Behnken design are some methods of RSM. Box - Behnken design (BBD) requires fewer runs than other RSM designs. When compared with Central Composite design and Three - level factorial designs, BBD was more efficient (Ferreira *et al*. 2007, Ay *et al*. 2009). Hence, BBD was used to statistically optimize the experimental parameters in this study.

Acid orange 7 (AO7) or Orange II is a frequently used azo textile dye for dyeing silk, wool and leather. The chemical structure of AO7 is made up of three benzene rings bridged by an azo group, and a sulphonyl group ($C_{16}H_{11}N_2NaO_4S$) having a molecular weight of 350.33 g/mol. AO7 is reported to be toxic to aquatic species and has associated environmental demerits (de–Luna *et al.* 2014). The conventional biological treatment of wastewater containing azo dyes is reported to be inefficient technology resulting in production of significant volume of toxic secondary sludge (Dai *et al.* 1995). Contrary to it Fenton's process is an efficient method resulting in complete mineralization (Dutta *et al.* 2001) with no toxic sludge generation. The present study, therefore, attempts to investigate the decolourisation of AO7 by Fenton's process; its optimization; and its statistical validation using BBD.

2. Experimental

2.1 Chemicals

AO7 (min. assay 85%) was obtained from Vishnu Chemicals, Gujarat, India; Ferrous sulphate (99%), Hydrogen peroxide solution (30% w/v), Sulphuric acid (97%), and Sodium hydroxide (97%) were obtained from CDH, India. All the experiments were carried out in triplicates using analytical grade chemicals and Grade I ultrapure water. Diluted solutions of Sulphuric acid (0.1 M) and Sodium hydroxide (1.0 M) were used to adjust the pH.

2.2 Experimental procedure

A Stock solution (50 mg/l) of AO7 was prepared in ultrapure water and was placed over a magnetic stirrer at 150 rpm for 24 hours to equilibrate AO7 dissolution. The experiments were conducted using 200 ml of the dye solution in a conical flask, continuously stirred using a magnetic stirrer at 150 rpm. The pH was adjusted to appropriate value using Sulphuric acid (0.1 M) and Sodium hydroxide (1.0 M). The experiments were conducted at varying concentrations (mg/l) of $FeSO_4$ (7.5-150), and H_2O_2 (1.0-7.0 mmol/l) at initial AO7 concentration of 50 mg/l. The effect of pH (2.5, 3.0, and 3.5) on percent removal of AO7 was also studied at optimized conditions of $FeSO_4$ and H_2O_2. The concentration of AO7 was monitored recording the absorbance of dye solution over Labtronics make LT-290 model of visible spectrophotometer at 490 nm (λ_{max}) at regular intervals of 30 seconds from 1 minute to 5 minutes, and later at an interval of 5 minutes till complete decolourisation of AO7 was observed.

Preliminary experiments were conducted to find the range of different parameters which were to be used in BBD of experiments. Concentration of Hydrogen peroxide and ferrous sulphate, pH and contact time were the variable parameters and dye removal (%) was considered the response to be maximized.

2.3 Experimental design

RSM is a useful method for optimization of process variables and can be widely used for experimental design. RSM can also determine the relationship between dependent and independent variables. It gives faster experimental results rather than one factor at a time approach (Arslan-Alaton *et al.* 2009). In the present study, BBD was used as it gives least number of runs compared to other designs. BBD is a rotatable quadratic design with no embedded factorial/fractional factorial points where the variable combinations are at the midpoints of the boundary of the variable space and are at the centre (Ay *et al*. 2009). BBD with four variable factors and three variable levels was used to investigate the effect of independent variables along with the effect of interactions between the variables. Mathematical relationship between response (Y) and independent variables (X_i) can be approximated by the following equation:

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X_1X_1 + b_{22}X_2X_2 + b_{33}X_3X_3$$

The coefficients (b_i) were obtained by correlating the experimental results with the response functions. The experiments were conducted using statistically designed combinations, and were randomized to reduce the effects of factors that are not included in the study.

Experimental data were analysed using Minitab ver. 17.1.0 software, fitted to the mathematical equation and coefficients were determined. Analysis of Variance (ANOVA) test was conducted to establish the model adequacy and predictability at 95% confidence level.

3. Results and discussion

All the experiments on decolourisation of AO7 using Fenton's process were run in triplicates and the results were averaged. Effect of concentration of H_2O_2 and $FeSO_4$ was investigated to optimize dye decolourisation at initial AO7 concentration of 50 mg/l. The effect of pH was also studied at optimized dosages of H_2O_2. The results so obtained are discussed below.

3.1 Effect of initial concentration of H_2O_2

To investigate the effect of initial concentration of H_2O_2 on the decolourisation of AO7, experiments were conducted for varying concentration of H_2O_2 (1.0 to 7.0 mmol/l at regular interval of 1.0 mmol/l) at fixed concentration of 10 mg/l of $FeSO_4$ and at pH 3. Contact time for decolourisation of AO7 decreased from 230 minutes to 120 minutes when initial concentration of H_2O_2 was increased from 1.0 to 5.0 mmol/l (Fig. 1). The contact time for complete decolourisation at 6.0 and 7.0 mmol/l remained stable at around 120 min. as was observed at 5.0 mmol/l. Therefore, H_2O_2 concentration of 5.0 mmol/l was observed as the optimum dose. Further increase in H_2O_2 had no effect on contact time for complete decolourisation. Similar increase in decolourisation of Red MX 5B dye was observed when concentration of H_2O_2 was increased from 20 mg/l to 200 mg/l. There was no significant improvement in decolourisation for concentration above 200 mg/l. Several other studies (Malik and Saha 2003, Muruganandham and Swaminathan 2004, Lucas and Peres 2006, Wang 2008) on various textile dyes confirm that decolourisation reaches a maximum and stabilizes with increasing dose of H_2O_2. Increase in H_2O_2 dose above this level has no effect on the decolourisation since recombination of $^{\bullet}OH$ radicals to H_2O_2 takes place and a scavenging behaviour results in no further decolourisation. Based on the results obtained, a range of 4.0-6.0 mmol/l of H_2O_2 was selected for BBD for optimization of this parameter and validation of results.

3.2 Effect of initial concentration of $FeSO_4$

A remarkable dependence of decolourisation of AO7 was observed on $FeSO_4$ concentration. The concentration of $FeSO_4$ was varied from 7.5 to 150 mg/l. With increasing concentration of $FeSO_4$ decolourisation of AO7 increased at a constant time. The time for complete decolourisation of AO7 decreased from 240 minutes to 5 minutes (Fig. 2) in experimental study.

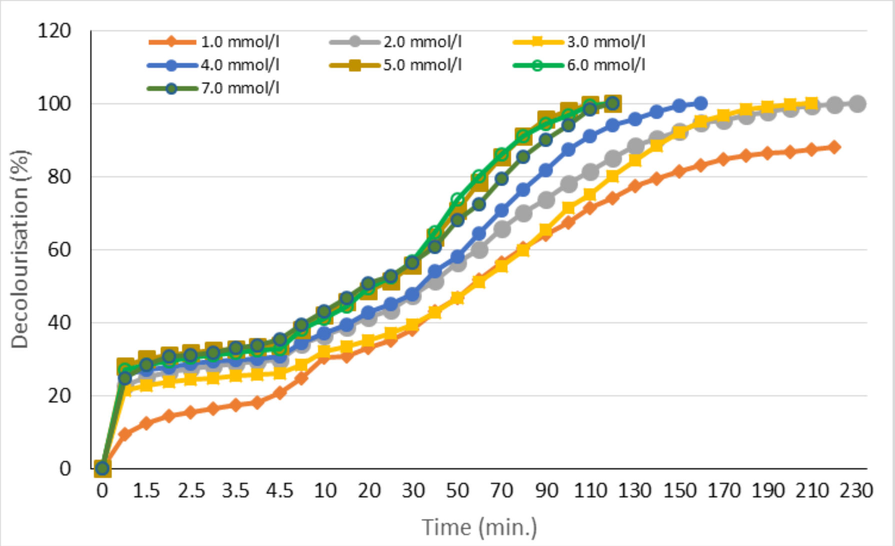

Fig. 1 Effect of H_2O_2 concentration (mmol/L) on decolourisation of AO7 (50 mg/L) at $FeSO_4$ 10 mg/L, and pH 3

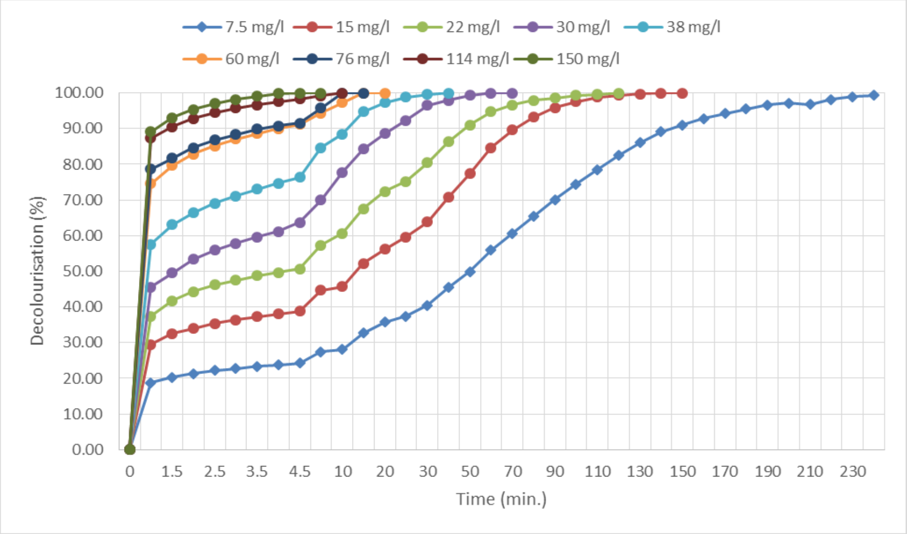

Fig. 2 Effect of $FeSO_4$ concentration (mg/L) on decolourisation of AO7 (50 mg/L) at H_2O_2 2.0 mmol/L, and pH 3

In the present study, for concentrations above 38 mg/l of $FeSO_4$, precipitation and colour due to ferric ions were observed. It is reported that (Sun *et al*. 2009) high Fe^{2+} dosages result in higher production of $^{\bullet}OH$ radicals and Ferric (Fe^{3+}) ions (Eq. (1)) in excess. Fe^{3+} ions tend to precipitate due to their non-solubility in aqueous medium. Similar results were obtained by Ramirez *et al*. (2009), for Fe^{2+} ions in range of 2.5×10^{-6} M to 2.0×10^{-5}M and reported that with increasing concentration of Fe^{2+} ions the rate of decolourisation increases. Another study (Chacon *et al*. 2006) reported 75%, 85% and 90% degradation of Acid Orange 24 for 7.16×10^{-5} M, 1.43×10^{-4} M and

1.07×10^{-4} M of Fe^{2+} ions, respectively. In a similar study (Sun *et al*. 2009), Fe^{2+} dosage was varied from 5.0×10^{-6} M to 3.5×10^{-5} M and percent decolourisation increased from 52% to 92% for Acid Orange G. The increase in ferrous ion concentration increases the rate of hydroxyl radical generation and hence the rate of decolourisation increases. Since, maximum decolourisation was observed at 38 mg/l (without precipitation of Fe^{3+} ions), the concentration range of 30-46 mg/l of $FeSO_4$ was selected for BBD.

3.3 Effect of pH

Variation of pH is very important parameter to be studied as stability of hydrogen peroxide varies with pH. Variation of pH with respect to contact time for complete decolourisation of dye is given in Fig. 3. It was observed that complete decolourisation of AO7 was observed within 10 min. at pH values of 2.8 and 3.0. It took 15 and 25 min. for complete decolourisation at pH of 3.3 and 3.5, and pH 2.5, respectively.

Similar results were reported (Elmorsi *et al*., 2010) for the decolourisation of Mordant Red 73 dye having maximum decolourisation efficiency at pH 3. In another study (Neamtu *et al*., 2003), decolourisation of Reactive Yellow 84 was found to be maximum (99%) at pH 3 for reaction time of 15 min. When pH is alkaline, hydrogen peroxide is destabilized and forms water and oxygen, also iron precipitates in the form of hydroxide and cannot react with H_2O_2 to form hydroxyl radicals. When pH is strongly acidic (pH<3.0) H_2O_2 is stable and doesn't react with ferrous ions. Our study is in confirmation with the published literature on effect of pH in dye decolourisation by Fenton's process. Therefore, the pH range of 2.5 to 3.5 was considered for BBD for optimization and validation of the results obtained in the study.

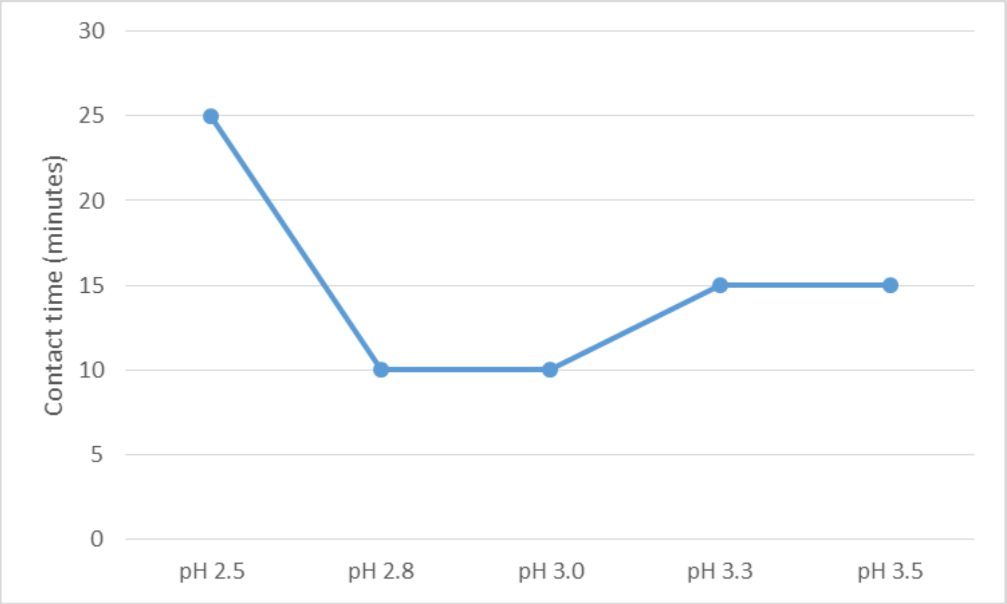

Fig. 3 Effect of pH on contact time for complete decolourisation of AO7 (50 mg/L) at H_2O_2 5.0 mmol/L, and $FeSO_4$ 38 mg/L

3.4 Experimental design and statistical analysis

BBD was used to optimize the decolourisation of AO7, defining the minimum and maximum levels for pH (2.5-3.5), H_2O_2 (4.0-6.0 mmol/l), $FeSO_4$ (30-46 mg/l), and time (5-15 min.). The ranges considered were chosen from the experimental results obtained in this study. The exploratory runs statistically designed by BBD are shown in Table 1. Factorial fit of the experimental data yielded the following regression equation for AO7 decolourisation:

$Y = - 352.5 + 27.8\ X_1 + 4.92\ X_2 + 156.7\ X_3 + 5.85\ X_4 – 1.44\ X_1X_1 – 0.0167\ X_2X_2 – 16.45\ X_3X_3 – 0.0895\ X_4X_4 – 0.082\ X_1X_2 – 2.46\ X_1X_3 – 0.182\ X_1X_4 – 0.876\ X_2X_3 – 0.0297\ X_2X_4 – 0.414\ X_3X_4$

Where Y is percent decolourisation of AO7, X_1 is H_2O_2 (mmol/l), X_2 is $FeSO_4$ (mg/l), X_3 is pH and X_4 is contact time (min.). Predicted values of percent decolourisation of AO7 (as obtained from model equation) were compared against the actual decolourisation observed in experimental results (Table 1). It is evident from the results that a good agreement is obtained between experimental and predicted values for percent decolourisation with average standard deviation of 0.93.

Table 1 Box-Behnken Design matrix and response factor results for decolourisation of Acid Orange 7

Run	**H_2O_2 (mmol/l)**	**$FeSO_4$ (mg/l)**	**pH**	**Contact time (min.)**	**Decolourisation (%)**	
					Predicted	**Observed**
1	0 (5)	+1 (46)	0 (3)	+1 (15)	102.0	100.0
2	0 (5)	0 (38)	-1 (2.5)	-1 (5)	84.6	86.9
3	-1 (4)	+1 (46)	0 (3)	0 (10)	99.6	99.7
4	-1 (4)	-1 (30)	0 (3)	0 (10)	93.2	95.4
5	0 (5)	0 (38)	0 (3)	0 (10)	100.0	100.0
6	+1 (6)	0 (38)	+1 (3.5)	0 (10)	98.5	100.0
7	-1 (4)	0 (38)	0 (3)	+1 (15)	100.0	99.2
8	-1 (4)	0 (38)	0 (3)	-1 (5)	90.4	88.0
9	+1 (6)	0 (38)	0 (3)	+1 (15)	100.4	100.0
10	0 (5)	0 (38)	-1 (2.5)	+1 (15)	94.5	97.6
11	-1 (4)	0 (38)	-1 (2.5)	0 (10)	88.0	87.6
12	0 (5)	-1 (30)	0 (3)	-1 (5)	89.1	92.2
13	-1 (4)	0 (38)	+1 (3.5)	0 (10)	98.7	100.0
14	0 (5)	0 (38)	0 (3)	0 (10)	100.0	100.0
15	0 (5)	+1 (46)	0 (3)	-1 (5)	96.5	96.9
16	0 (5)	0 (38)	+1 (3.5)	-1 (5)	94.9	93.5
17	0 (5)	+1 (46)	-1 (2.5)	0 (10)	96.7	96.6
18	+1 (6)	0 (38)	0 (3)	-1 (5)	94.4	92.4
19	0 (5)	-1 (30)	0 (3)	+1 (15)	99.3	100.0
20	0 (5)	0 (38)	0 (3)	0 (10)	100.0	100.0
21	0 (5)	-1 (30)	+1 (3.5)	0 (10)	99.9	97.2
22	0 (5)	+1 (46)	+1 (3.5)	0 (10)	98.0	100.0
23	+1 (6)	-1 (30)	0 (3)	0 (10)	96.7	98.3

Table 1 Continued

Run	H_2O_2 (mmol/l)	$FeSO_4$ (mg/l)	pH	Contact time (min.)	Decolourisation (%)	
					Predicted	Observed
24	0 (5)	-1 (30)	-1 (2.5)	0 (10)	84.6	79.8
25	+1 (6)	0 (38)	-1 (2.5)	0 (10)	92.6	92.5
26	0 (5)	0 (38)	+1 (3.5)	+1 (15)	100.7	100.0
27	+1 (6)	+1 (46)	0 (3)	0 (10)	100.5	100.0
28	0 (5)	0 (38)	0 (3)	0 (10)	100.0	100.0

Table 2 Results of ANOVA-test for response percent decolourisation

Source	Sum of squares	Degrees of freedom	Mean square	F-ratio	P-value
Model	663.253	14	47.375	6.85	0.001
X_1 (H_2O_2)	14.674	1	14.674	2.12	0.169
X_2 ($FeSO_4$)	77.572	1	77.572	11.22	0.005
X_3 (pH)	205.924	1	205.924	29.78	0.000
X_4 (Contact time)	183.535	1	183.535	26.54	0.000
X_1X_1	12.492	1	12.492	1.81	0.202
X_2X_2	6.843	1	6.843	0.99	0.338
X_3X_3	101.497	1	101.497	14.68	0.002
X_4X_4	30.050	1	30.050	4.35	0.057
X_1X_2	1.716	1	1.716	0.25	0.627
X_1X_3	6.027	1	6.027	0.87	0.368
X_1X_4	3.312	1	3.312	0.48	0.501
X_2X_3	49.140	1	49.140	7.11	0.019
X_2X_4	5.641	1	5.641	0.82	0.383
X_3X_4	4.285	1	4.285	0.62	0.445
Residual	89.888	13	6.914		
Lack of fit	89.888	10	8.989		
Pure error	0.000	3	0.000		
Total	753.142	27			

Results of ANOVA test (Table 2) were obtained for each response and quality of model fitting was analysed by the value of regression coefficient (R^2). R^2 value (0.88) indicated a good fit by the model as suggested in literature (Arslan-Alaton *et al.* 2009, Torrades and Garcia-Montano 2014). The model F-value was calculated by dividing the model mean square by residual mean square. Calculated F-value of model was 6.85, and it was higher than tabulated value (2.51) indicating that the model is significant. The student t-test helped identify significant variables and interactions. From these results it was observed that X_2 ($FeSO_4$ concentration), X_3 (H_2O_2 concentration) and X_4 (contact time) had a positive effect on the response ($P<0.05$ for 95% confidence level) in this study.

3.5 Effect of variable parameters (H_2O_2, $FeSO_4$, pH, and time) and their interactions

The Minitab (ver. 17.1.0) was used to produce 2-D contour plots of the model-predicted responses, keeping two variables constant and the others varying within the experimental ranges. It was utilized to assess the interactive relationships between the process variables and response. It was observed that as H_2O_2 and $FeSO_4$ concentration increased, there was a substantial increase in AO7 decolourisation, reaching the maximum at around 5 mmol/l of H_2O_2 and 42 – 44 mg/l of $FeSO_4$ concentration. Deviation from the optimized values resulted in reduced response at constant pH and time (as shown in Figs. 4 and 5(a)). This is attributed to co-precipitation of Fe^{3+} and OH^- ions. Percent decolourisation obtained as a function of initial H_2O_2 concentration and pH is depicted in Fig. 5(b). It was observed that maximum decolourisation in pH range of 3.1 to 3.3 and H_2O_2 in the range 4.5 to 5.3 mmol/l takes place. The results obtained in univariate experiments are in confirmation with the predicted response. Fig. 5(c) illustrates the effect of initial concentration of H_2O_2 and time on decolourisation of AO7.

As concentration of H_2O_2 increased (4.0-5.0 mmol/l), the time for complete decolourisation decreased from 15 to 10 minutes. Percent decolourisation varies significantly at low $FeSO_4$ concentrations and pH in lower range (<2.5) (Fig. 6(a)). The maximum response being observed at pH of around 3.1 and is maintained over a wide range for $FeSO_4$ concentration (32-45 mg/l). Similarly, the time for complete decolourisation was maximum at around 14 minutes at pH of 3.1. Based on the model prediction and interaction of variable parameters, optimized values of BBD for variable factors were deduced (Fig. 7). The optimized values based on BBD were found to be 4.97 mmol/l of H_2O_2, 40.83 mg/l of $FeSO_4$, 3.1 of pH, and 13.6 minutes contact time.

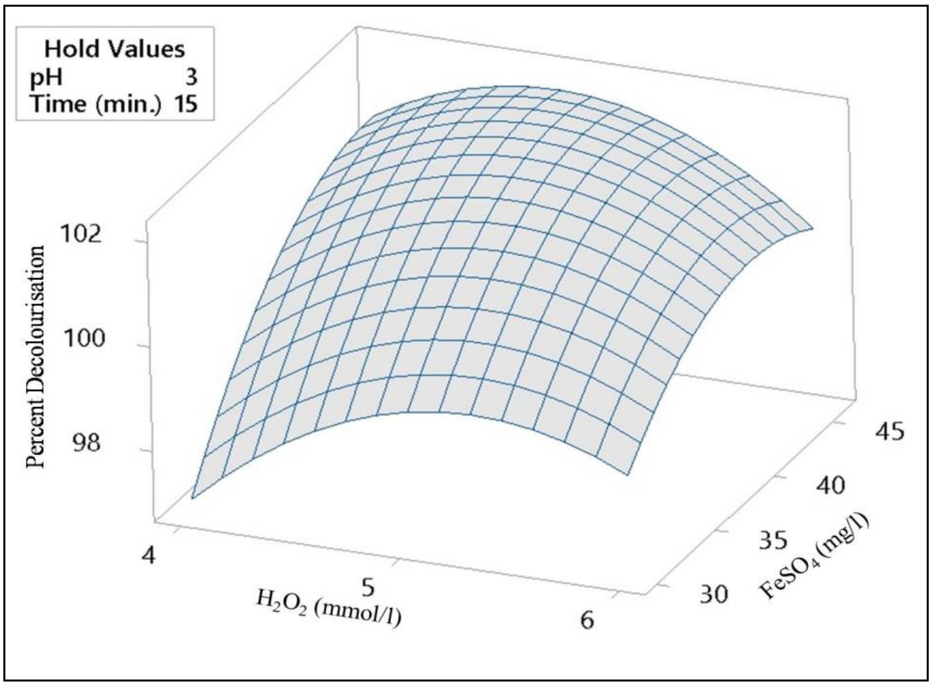

Fig. 4 Response surface plot of percent decolourisation of the AO7 as a function of H_2O_2 (mmol/L) and $FeSO_4$ (mg/L)

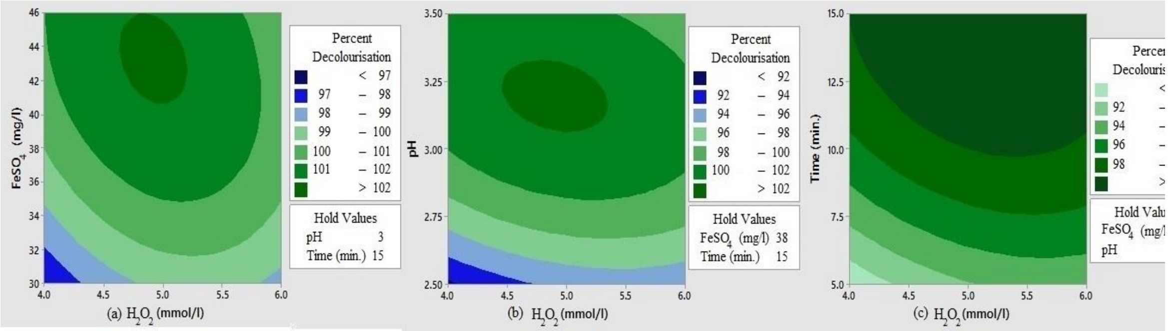

Fig. 5 Contour plots of percent decolourisation of AO7 as a function of initial H_2O_2 concentration and (a) $FeSO_4$ concentration; (b) pH; and (c) time

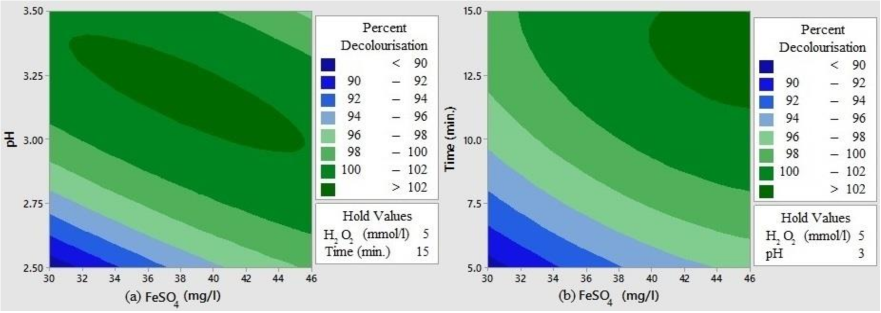

Fig. 6 Contour plots of percent decolourisation of AO7 as a function of initial $FeSO_4$ concentration and (a) pH and (b) time

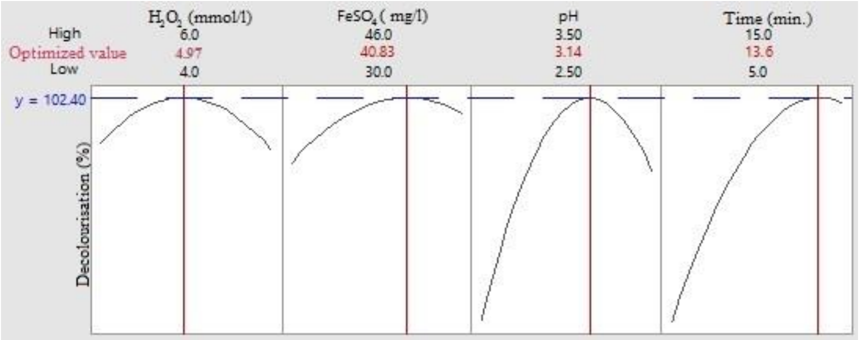

Fig. 7 Optimization plot for decolourisation of AO7

4. Conclusions

Based on the results obtained, it was concluded that Fenton's process is an efficient method for decolourisation of AO7. The concentrations of H_2O_2 (mmol/l) and $FeSO_4$ (mg/l) are important regulators for decolourisation efficiency at pH~3. H_2O_2 dissociates into OH^- and $^\bullet OH$ radicals in presence of Fe^{2+} ions; and $^\bullet OH$ radicals result in cleavage of azo bond of AO7, and hydroxylation/epoxidation of aromatic rings resulting in ring opening and subsequent degradation of AO7.

Concentration of Fe^{2+} increases the efficiency of Fenton's process to a maximum value at optimized conditions. Further increase in Fe^{2+} concentration results in its conversion to Fe^{3+} which is insoluble and precipitates as Ferric hydroxide. This results in scavenging of chemical species responsible for decolourisation of AO7. The experimental and model-predicted response was found to validate each other with a significant R^2 value of 0.88.

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