

Decoloration of the Reactive Blue Dye, KN-R

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Abstract: The oxidation using UV-Fenton reagent has been found to be a promising treatment method for the effective decolorization and degradation of dyes. The decolorization of the reactive blue dye KN-R was investigated using Fenton and UV/Fenton processes. The effects of solution pH, initial dye, H_2O_2 , Fe^{2+} concentrations, respectively, were studied and optimal conditions determined. The optimized treatment conditions are the following: pH 3.0, 30 mg L^{-1} (Fe^{2+}), 10.2 g L^{-1} (H_2O_2) for a reaction time of 30 min. The KN-R dye degradation was found to be dependent on the dye concentration such that the higher the dye concentration, the lower the decoloration and degradation efficiencies. The UV/Fenton process showed higher decoloration rate than the Fenton process and 98% was achieved in about 10 min of the reaction time. The effect of iron source and NaCl were studied. Finally, kinetics involved in KN-R degradation were also calculated and the rate constants were found to be proportional to hydrogen peroxide concentration as well as ferrous ions concentration.

Key words: KN-R dye, fenton, UV-fenton, decoloration

INTRODUCTION

Dyes have been used for over 5000 years. Synthetic dyes quickly replaced the traditional natural dyes due to their low cost, their vast range of new colors and their better properties upon the dyed materials. However, 1000 of synthetic dyes are raising concerns due to their negative environmental effects. Synthetic dyes are the major water contaminants (Brown *et al.*, 1981; Vaidya and Datye, 1982). Textile wastewater introduces color and toxicity to aquatic systems (Muruganandham and Swaminathan, 2004). The color is objectionable aesthetically and it also reduces light penetration into the water thereby decreasing the efficiency of photosynthesis in aquatic plants hence impacting on their growth and development (AL-Degs *et al.*, 2000). Furthermore, their presence in drinking water constitutes a potential human health hazard (Boeningo, 1994).

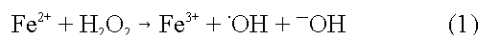
Most of pollutants, except color, can be reduced by chemical, physical or biological methods. Unfortunately, water soluble dyes such as acid dyes and reactive dyes are not easily removed in conventional biological treatment processes or the conventional physico-coagulation methods due to their high solubility and non-biodegradability (Juang *et al.*, 1997). Chemical treatment by chlorine, the most widely used chemical oxidant in the

past, has been restricted in many countries due to the possible health effects from the generation of organochlorine compounds (White, 2005).

Recently, developed techniques include the so called Advanced Oxidation Processes (AOPs). AOPs are designed to oxidize organic compounds into CO_2 , H_2O and inorganic ions, or biodegradable compounds and to facilitate oxidation processes involving hydroxyl radicals (Nogueira *et al.*, 2005). Generation of the hydroxyl radical has been accomplished with the following technologies: ultraviolet (UV) irradiation (Legrini *et al.*, 1983), ozonation (Somich *et al.*, 1992; Hapeman *et al.*, 1997; Hoigne and Bader, 1983), ozonation in combination with UV or hydrogen peroxide (Staelin and Hoigne, 1982; Adams *et al.*, 1994; Mokrini *et al.*, 1997), Fenton reagent oxidation (Pignatello and Sun, 1995; Pignatello *et al.*, 1999; Li *et al.*, 1997; Pignatello, 1992; Huston and Pignatello, 1999; Engwall *et al.*, 1999; Sun and Pignatello, 1993a, b; Fallmann *et al.*, 1999; Howsawkung *et al.*, 2001; Pratap and Lemley, 1998; Pignatello and Baehr, 1994) and photocatalysis with titanium dioxide in combination with UV and oxygen (Gimenez *et al.*, 1997). Fenton reagent is composed of iron salt and hydrogen peroxide which has been used to produce the highly reactive hydroxyl radical (Malik and Saha, 2003).

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It participates in nonspecific oxidation of many toxic organic compounds. In the treatment method for inevitable secondary considerations that go dye wastewater, it is important to be aware of the beyond the actual removal of color. These considerations include: sludge production and handling cost requirements, the level of operational skill required, the operational and a maintenance attention needed, the long-term system reliability and the total system costs (Loncaric and Bozic, 2004). The oxidation using Fenton reagent and photo-Fenton reagent has been found to be a promising treatment method for the effective decolorization and degradation of dyes. Compared with other oxidation processes, the Fenton reagent is relatively cheap, easily operated and maintained (Swami Nathan *et al.*, 2003). The use of $\text{Fe}^{2+}/\text{H}_2\text{O}_2$ as an oxidant for wastewater treatment is attractive since iron is highly abundant and non toxic and a 30% hydrogen peroxide aqueous solution is easy to handle and has no known adverse environmental effects (Kang *et al.*, 2000).



Operational parameters of Fenton type processes that directly influence their efficiency are iron concentration, source of iron catalysts (iron powder, ferrous or ferric salts), H_2O_2 concentration, iron catalysts/hydrogen peroxide ratio (Fenton reagent), pH and treatment time (Brewer, 1941). This also agrees with Malik and Saha (2003) who reported that the color removal rate is strongly dependent on the initial concentration of the dye, Fe^{2+} and H_2O_2 .

Reactive brilliant blue dye, KN-R is typical and in common use in textile, dyeing and printing industries. As, it causes great pressure on the potential of pollution of water environment, a proper treatment is necessary before discharge into the environment. Most of the researches done about it were mainly based on biological treatments which take a long time. Also, chemical based methods were used but dealt with small concentrations of KN-R. This research is handling higher concentration of the dye such as 200 mg L^{-1} .

The objective of the current study is to evaluate the dependence factors for the color removal rate such as the initial concentration of the dye, KN-R, Fe^{2+} , H_2O_2 and the pH. The influence of iron sources and NaCl as it regulates the speed and the depth of reactive and direct dyeing of cotton, was also examined as well as the kinetics involved in dye decolorization.

MATERIALS AND METHODS

The reactive blue dye, KN-R came from a commercial source and was used without further purification. Figure 1 shows the chemical structure of KN-R, empirical

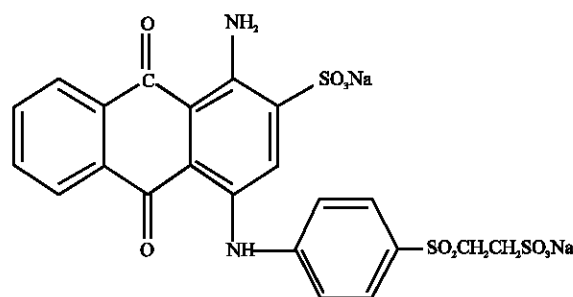


Fig. 1: Chemical structure of the KN-R dye

formula: $\text{C}_{22}\text{H}_{16}\text{N}_2\text{Na}_2\text{O}_{11}\text{S}_3$. All analytically grade, Ferrous sulfate heptahydrate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) used as the source of Fe^{2+} was purchased from Tianjin Fuchen chemicals co and Hydrogen peroxide (30% volume solution) obtained from Tianjin Hengxing chemical preparation co. was used to generate hydroxyl radicals.

Procedure: All solutions were prepared in distilled water in all experiments. With appropriate concentrations, a known amount of H_2O_2 and $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ were added to 500 mL of the dye solution in 1000 mL Pyrex Erlenmeyer flask. 1 M H_2SO_4 and 1 M NaOH were used to adjust the pH of the studied dye solution.

A magnetic stirrer provided a continuous and a homogenous mixing and 3 drops of a quenching solution containing KI, Na_2SO_3 , $\text{K}_2\text{H}_2\text{PO}_4$ and NaOH (0.1M) each was used to stop the reaction so as to allow into the samples taken at different reaction times to undergo spectrophotometric readings.

All the experiments were carried out under open Bair condition. In UV-Fenton process, the above procedure was repeated but with a mercury UV lamp (30 W, UV-C, $\lambda_{\text{max}} = 254 \text{ nm}$) placed above a 1000 mL Pyrex Erlenmeyer flask containing the dye sample. The reaction time was recorded when the UV lamp was turned on.

Analytical methods: $\text{Fe}^{2+}/\text{H}_2\text{O}_2/\text{KN-R}$ dye solution with 200 mg L^{-1} (unless otherwise indicated) concentrations was freshly prepared with $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, H_2O_2 and KN-R dye stock solution.

The pH of the dye solution was measured by using PHS-3C pH meter (Shanghai precision and scientific instrument co). At regular intervals within 30 min of reaction time (2 min for the first 10 min, then 4 min intervals), 5 mL of sample solutions were withdrawn to undergo spectrophotometric analysis at 592 nm by UNICO 7200 spectrophotometer manufactured by Shanghai Unico Company.

Concentration of dye solution at different times were obtained by surveying the absorbance at maximum wavelength ($\lambda_{\text{max}} = 592 \text{ nm}$) and computing from the calibration curve based on Beer Lambert's law

(Brewer, 1941). The absorbance at 592 nm is due to the color of the dye and it is used to monitor the decolorization of the dye which is analyzed as follows:

$$\text{Dye decolorization (\%)} = \frac{1 - C_{\text{dye},t}}{C_{\text{dye},0}} \quad (2)$$

Where,

$C_{\text{dye},t}$ and $C_{\text{dye},0}$ are the concentrations of dye at reaction time t and 0 , respectively.

Kinetically, KN-R dye decoloration was evaluated by the logarithm of the ratio of the initial concentration to the concentration at a given time $\{\ln(C_0/C)\}$ vs. time (t) (Fogler, 2006) plotted (not shown) using the experimental data. The rate constant k_{ap} was determined by calculating the slope of the line obtained. The half lives of dye decoloration were obtained by the following formula: $\ln 2/k_{\text{ap}}$.

In order to avoid variations resulting from competitive effects of intermediates, pH change, etc, we only considered data taken from the first 10 min of reaction.

Note that among the reactions taking place at the Fenton and UV-Fenton processes, the reaction between OH. Radicals and the dye is the rate -determining step.

The rate equation can be given by:

$$r = -dC/dt = k_{\text{OH}}[\text{OH}]C \quad (3)$$

where, C is the concentration of the dye and k_{OH} is the reaction rate constant.

Assuming that OH radicals rapidly achieve a constant steady-state concentration in the solution, the rate equation can also be written as:

$$r = -dC/dt = k_{\text{OH}}[\text{OH}]C = k_{\text{ap}} C \quad (4)$$

where, k_{ap} is the apparent pseudo-first Border constant (Huston and Pignatello, 1999; Malato *et al.*, 2001).

RESULTS AND DISCUSSION

Effect of the initial KN-R dye concentration: It is very important to study the dependence of the removal efficiency on the initial concentration of the dye. The decoloration of the dye takes place due to the hydroxyl radicals produced during Fenton process (Xu, 2001):

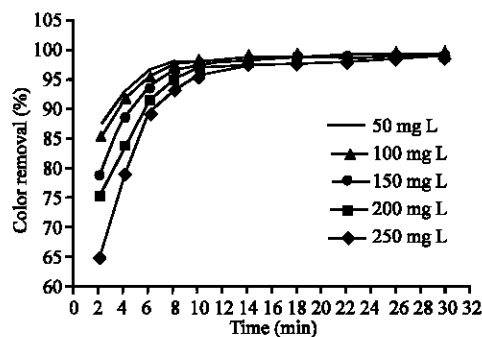
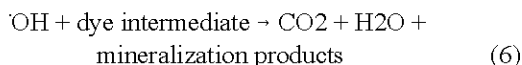
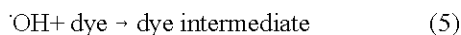


Fig. 2: Effect of the initial concentration of KN-R in fenton process, $(\text{H}_2\text{O}_{2[\text{liq}]})_0 = 10.2 \text{ g L}^{-1}$, $(\text{Fe}^{2+})_0 = 0.1 \text{ M}$ and $\text{pH} = 3$

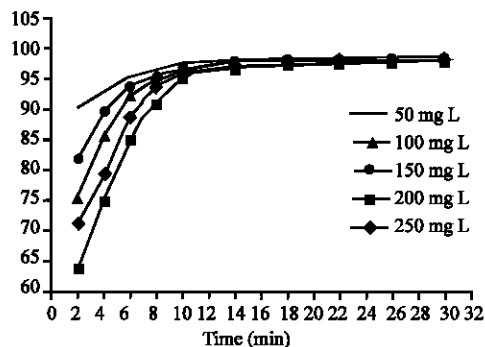


Fig. 3: Effect of the initial concentration of KN-R in UV-fenton process, $(\text{H}_2\text{O}_2)_0 = 10.2 \text{ g L}^{-1}$, $(\text{Fe}^{2+})_0 = 0.1 \text{ M}$ and $\text{pH} = 3$

Table 1: K_{ap} , rate constants and half-lives of KN-R dye in different dye concentrations

Dye conc. (mg L^{-1})	K_{ap} (min ⁻¹)	R^2	$T_{1/2}$ (min)
50	0.293	0.97	2.36
100	0.273	0.98	2.54
150	0.257	0.98	2.69
200	0.231	0.9971	3.00
250	0.218	0.99	3.17

As, it can be clearly seen from the Fig.2 and 3, the dye concentration had a great influence on the color removal efficiency. It was observed that for both Fenton and UV-Fenton processes, the decolorization decreases with increase in initial concentration of dye.

The reason behind is that the increase in the initial concentration of the dye lies in constancy of the hydroxyl radicals concentrations for all the dye molecules and therefore the removal decreases.

Once the concentration of the dye is increased, it also causes the dye molecules to absorb light and photons never reach the photo-catalyst surface, thus the photo degradation efficiency decreases (Daneshavar *et al.*, 2005). Kinetic data presented in Table 1 shows that Photo-Fenton process decolorizes dyes more efficiently at lower

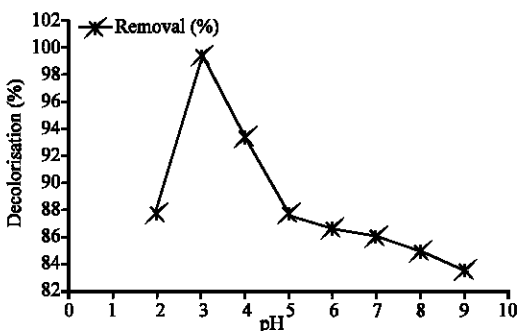
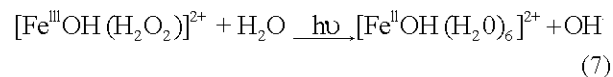


Fig. 4: Effect of the initial pH in Fenton process, $(H_2O_2)_0 = 10.2 \text{ g L}^{-1}$, $(Fe^{2+})_0 = 0.1 \text{ M}$

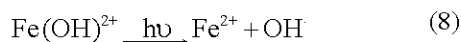
dye concentration at some extent in such a way that the lower the dye concentration, the higher the rate reaction and consequently, the shorter the half life reaction.

Effect of initial pH on the KN-R decolorization: The pH is an important parameter which directly or indirectly affects the decolorization of a dye. It influences the generation of hydroxyl radicals and the concentration of Fe^{2+} and thus the oxidation efficiency.

It has been reported that both Fenton and photo-Fenton process could remove pollutants under acidic condition (Kang *et al.*, 2000). Similarly, our results showed that the decolorization was greatly affected by the initial pH. At pH =3, more than 96.0% of the color was removed by 6 min while for the other pHs none could reach this value at 30 min of their reaction time. Maximum decolorization efficiency in 30 min was up to 99.4% at pH 3 but decolorization rate were significantly decreasing up to 83.5% at pH 9. As Fig. 4 shows, pH 3 was found to be the optimum pH in Fenton processes. This finding is in agreement with that of Muruganandham and Nathan (2004) who also determined that pH of 3 was the optimum pH for Fenton and photo-Fenton processes. At pH~3, the predominant species is the $(Fe^{3+}OH(H_2O)_5)^{2+}$ complex which is able to undergo excitation. This excitation is followed by electron transfer producing $Fe(II)$ aqua complex and OH radical (Ciesla *et al.*, 2004):



Or more simplified (Poulain *et al.*, 2003):



At pH above 4, the degradation strongly decreases because iron starts to precipitate as hydroxide and the coagulation of Fe^{3+} complex formed reduced the catalysis of Fe^{2+} .

Table 2: K_{sp} rate constants and half-lives of KN-R dye in various pHs ($[H_2O_2]_0 = 10.2 \text{ g L}^{-1}$, $[Fe^{2+}]_0 = 0.1 \text{ M}$)

pH	K_{sp} (min^{-1})	R^2	$T_{1/2}$ (min)
2	0.0757	0.99	9.15
3	0.29	0.99	2.39
4	0.106	0.99	6.53
5	0.0999	0.97	6.93
6	0.098	0.94	7.07
7	0.0735	0.96	9.43
8	0.0597	0.99	11.61
9	0.0437	0.98	15.86

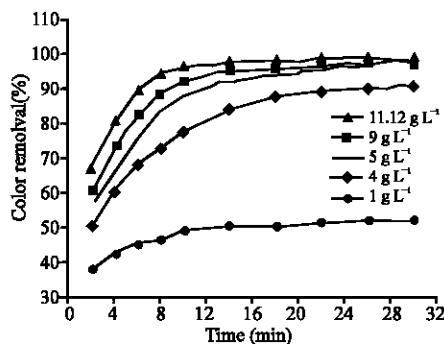


Fig. 5: Effect of the initial (H_2O_2) in Fenton process: $(Fe^{2+})_0 = 0.1 \text{ M}$, $\text{pH} = 3$

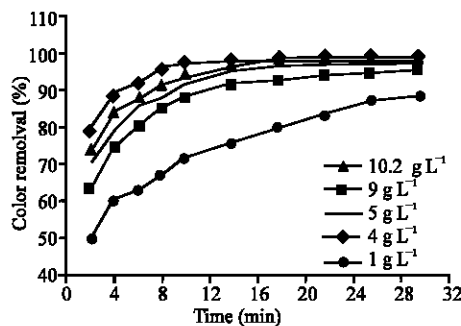


Fig. 6: Effect of the initial (H_2O_2) in photo-Fenton Process, $(Fe^{2+})_0 = 0.1 \text{ M}$, $\text{pH} = 3$

In addition, the oxidation potential of hydroxyl radical is known to decrease with increasing pH. At pH below 2, Hydrogen peroxide can stabilize, probably solvating a proton to form an axonium ion (H_3O^+). An axonium ion makes peroxide electrophilic to enhance its stability and presumably to reduce the reactivity with Fe^{2+} (Braun and Oliveros, 1997; Chen *et al.*, 1997). Then there is a hydroxyl radical scavenging effects of H^+ ions resulting in decrease in the removal efficiency.

Table 2 also proves that pH 3 is the optimal pH for the KN-R decoloration where its apparent rate constant is the highest and resulting in shorter half life time.

Effect of initial H_2O_2 concentration: Hydrogen peroxide concentration affects the decolorization of the dye. Figure 5 and 6 show that the color removal increases with the

Table 3: K_{app} , rate constants and half-lives of KN-R dye in various H_2O_2 concentrations ($[Fe^{2+}]_0 = 0.1\text{ M}$, $pH=3$)

H_2O_2 (g)	K_{app} (min^{-1})	R^2	$T_{1/2}$ (min)
10.2	0.3054	0.99	2.27
9	0.1743	0.99	3.97
5	0.1577	0.98	4.39
4	0.1458	0.99	4.75
1	0.0682	0.97	10.16

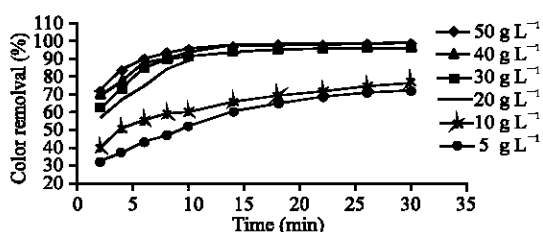
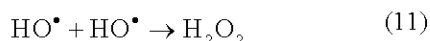
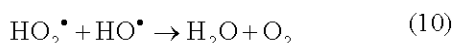
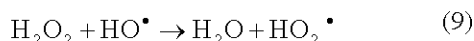


Fig. 7: Effect of the initial $FeSO_4$ in Fenton process, (H_2O_2)₀ = 10.2 g L⁻¹, pH= 3

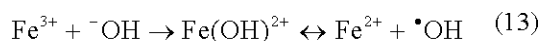
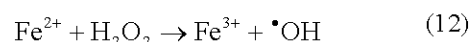
increase in the concentration of H_2O_2 . This can be explained on the basis that at higher concentration of H_2O_2 , more hydroxyl radicals are produced which degrade more dye molecules. Even if degradation of dye is proportional to the H_2O_2 concentration, very high concentration causes the scavenging effect that results in decrease in the concentration (number) of hydroxyl radicals due to the recombination of these radicals in reaction with H_2O_2 as expressed in Eq. 9-11 (Ghaly *et al.*, 2001).



From the results presented in Table 3, it is seen that the apparent rate of the dye decoloration is proportional to H_2O_2 concentration. The same Table 3 shows that the half life is inversely proportional to the H_2O_2 concentration, where higher to H_2O_2 concentration results in shorter half life time and vice-versa.

Effect of initial Fe^{2+} concentration: This study investigated the effect of Fe^{2+} concentration on the decolorization of the KN-R. Various concentrations of Fe^{2+} were used in order to determine its optimum original concentration. The results (Fig. 7) show that the decolorization was faster in the early stage of the reaction than that in the later stage. This may be because ferrous ion catalyses H_2O_2 to form hydroxyl radicals quickly in the initial stages of the reaction.

The results further show that the color removal increased from 72.1-98.8% with the addition of Fe^{2+} from 5-30 g L⁻¹ at 30 min. This indicates that Fe^{2+} as a catalyst can significantly accelerate the decomposition of H_2O_2 resulting in production of more hydroxyl radicals thus increasing the decoloration rate. However, the decolorization of KN-R began to decrease when the concentration of Fe^{2+} was higher than 30 g L⁻¹. This shows an excess Fe^{2+} that has a negative effect on the decolorization of the dye. The decrease in decoloration at higher Fe^{2+} concentrations was caused by the competition of Fe^{2+} and dye molecules on hydroxyl radicals resulting in the production of excess Fe^{3+} which undergoes a reaction with hydroxyl ions to form $Fe(OH)^{2+}$ which has a strong absorption and as a result the strength of UV light would decrease (Eq. 12-14) (Titus *et al.*, 2004; Zhao *et al.*, 2004).



Even if there are more OH radicals generated in Eq. 14 to decompose more dyes, color resurgence caused by Fe^{2+} intermediate may also lead to the decrease of decolorisation.

The experiments presented in Fig. 7 showed that 30 g L⁻¹ of Fe^{2+} can be used as an optimum concentration for both Fenton and photo Fenton processes.

Table 4 shows that the apparent rate of the dye decoloration is proportional to the ferrous iron concentration up to the optimal value (30 gL of Fe^{2+}) after which slows down. The same tendency is observed for their respective half lives.

The proportionality observed in rate constants and Fenton reagent concentrations as shown in Table 3 and 4 is presumably because of more OH radicals being generated (Alshamsi *et al.*, 2007).

Effect of iron source: Given that Fenton process involves the Iron ions, this study investigated the effected of iron sources by comparing the results obtained by the use of Fe^{2+} and Fe^{3+} . The results presented in Fig. 8 and 9 show that in both Fenton and UV Fenton processes, higher decolorization in 30 min is achieved with using Fe^{2+} with about 6 and 3% ahead, respectively. The results presented in Table 5 also shows that Fe^{2+} with or without UV are able to decolorize the dye faster than Fe^{3+} with or

Table 4: Kap. rate constants and half-lives in various ferrous ion concentrations, ($[H_2O_2]_0 = 10.2 \text{ g/L}$, $pH = 3$)

Fe ²⁺ g/L	Kap. (min ⁻¹)	R2	T1/2 (min)
5	0.0437	0.99	15.86
10	0.049	0.91	14.14
20	0.172	0.98	4.03
30	0.2304	0.99	3.01
40	0.1984	0.98	3.49
50	0.19	0.96	3.64

Table 5: Kap. rate constants and half-lives of KN-R dye in various iron sources, ($[H_2O_2]_0 = 10.2 \text{ g/L}$, $pH = 3$)

Iron source	Kap. (min ⁻¹)	R2	T1/2 (min)
Fe ³⁺	0.09	0.99	7.701635
Fe ³⁺ /uv	0.2429	0.97	2.853632
Fe ²⁺	0.131	0.99	5.2912
Fe ²⁺ /uv	0.3213	0.98	2.157321

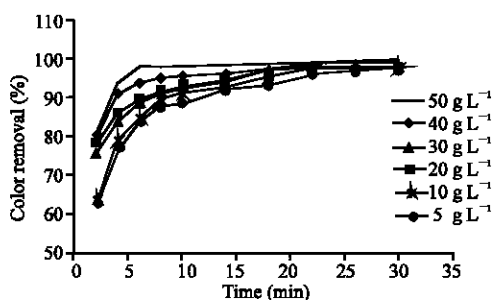


Fig. 8: Effect of the initial FeSO₄ concentration in UV-Fenton Process, ($[H_2O_2]_0 = 10.2 \text{ g L}^{-1}$, $pH = 3$)

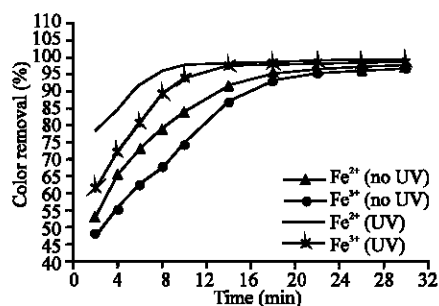


Fig. 9: Effects of iron sources: ($[H_2O_2]_0 = 10.2 \text{ gL}^{-1}$, $pH = 3$) Effects of NaCl

without UV, respectively. As, it can be seen from the Table 5, the half lives determined for respective decoloration prove the above remarks where Fe²⁺ lowers the life time compared to Fe³⁺ system.

The reason behind the decrease in decolorization when using Fe³⁺ is due to the regeneration of iron through the catalytic cycle (Eq. 1 and 15) which was inhibited by organic ligands produced during the treatment (Kang *et al.*, 2000; Tarr, 2003).

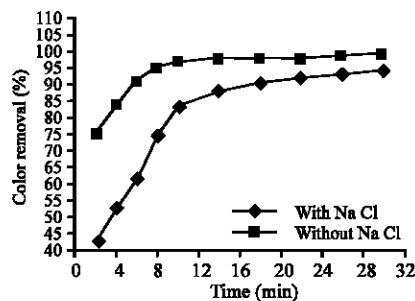
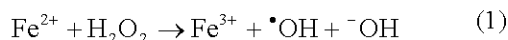


Fig. 10: Effect of NaCl on decolorisation of KN-R in fenton process: ($[H_2O_2]_0 = 10.2 \text{ g L}^{-1}$, $[Fe^{2+}]_0 = 0.1 \text{ M}$, $pH = 3$)

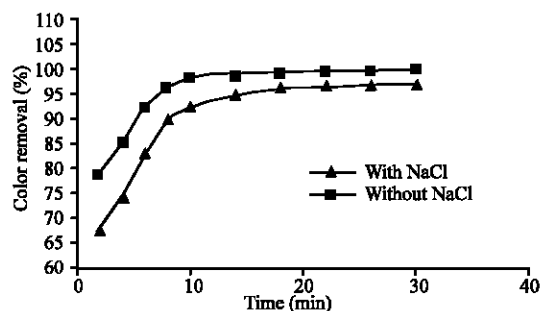
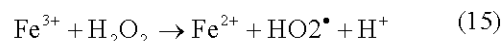


Fig. 11: Effect of NaCl in U.V. Fenton Process, ($[H_2O_2]_0 = 10.2 \text{ g L}^{-1}$, $[Fe^{2+}]_0 = 0.1 \text{ M}$, $pH = 3$)



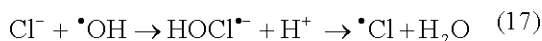
The effect of NaCl on the decolorization of KN-R dye has been studied. The reason is that this salt is generally found in the textile waste stream. Effluents containing a high content of NaCl results in a permeate with a comparable concentration and since, NaCl regulates the speed and the depth of reactive and direct dyeing of cotton, a higher concentration has a significant effect on the color of the dyed cotton by hampering the reusability for its dyeing (Hitchcock *et al.*, 1998). The results shown in Fig. 10 and 11 indicate that the addition of 0.1 M of salt decreases 32 and 11% of the decoloration at first 2 min of reaction in Fenton and UV Fenton processes, respectively.

In the overall reaction of 30 min, the results showed that in the presence of NaCl, 94.2 and 96.7% decoloration of KN-R was achieved in both Fenton and UV-Fenton processes, respectively. It can be clearly seen that the NaCl affects the decoloration rate with a 5 and 3 decrease of decoloration percentage.

Table 6: K_{sp} , rate constants and half-lives of KN-R dye with (+) or without (-) NaCl, ($[H_2O_2]_0 = 10.2 \text{ g L}^{-1}$, $[Fe^{2+}]_0 = 0.1 \text{ M}$, pH=3)

System	K_{sp} (min^{-1})	R^2	$T_{1/2}$ (min)
UV-Fenton (+)	0.1905	0.98	3.63
UV-Fenton (-)	0.3213	0.98	2.15
Fenton (+)	0.1543	0.97	4.49
Fenton (-)	0.2859	0.99	2.42

From the results, a decrease of removal efficiency is due to the scavenging effect of chloride ion (Eq. 16 and 17) (Muruganandham and Swaminathan, 2004).



From the Table 6, the experiments proved that the presence of NaCl delays the dye degradation by showing a smaller rate constant compared to the results where no NaCl was introduced.

The Table 6 shows how longer it takes to decolorize a half of its concentration when Fenton and /or UV-Fenton process is taking place and in presence of NaCl.

CONCLUSION

The present research, investigated the decolorization of the reactive blue dye, KN-R with Fenton and UV/Fenton processes. KN-R was found to decolorize rapidly and efficiently with Fenton reagent, but UV-Fenton process even showed a better decolorization. The decolorization was dependent on many factors such dye concentration, sample pH, iron source and concentration and the hydrogen peroxide concentration. The optimized decolorization condition is pH 3.0; $30 \text{ g L}^{-1} \text{ Fe}_2\text{SO}_4 \cdot 7\text{H}_2\text{O}$; and $10.2 \text{ g L}^{-1} \text{ H}_2\text{O}_2$ for a period of 30 min. It was found that NaCl could inhibit the Fenton and UV-Fenton with a decoloration decrease of 5 and 3%, respectively. The study identified the apparent rate of dye decolorization to be first order and proportional H_2O_2 concentration and ferrous ions concentration as well as the initial dye concentration in respect to the optimal value as well as the optimal pH 3. This study examined the influence of iron source and found that ferrous ions are better than ferric ones in Fenton processes.

Evidently, the KN-R decolorisation was effectively and rapidly achieved by Fenton and UV-Fenton processes due to the generated powerful oxidizing agent OH.

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