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Optimized treatment of wastewater containing natural rubber latex by coagulation-flocculation process combined with Fenton oxidation

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Abstract

In this study, the effectiveness of combined coagulation-flocculation (CF) and Fenton oxidation (FO) in the treatment of wastewater containing natural rubber latex (NRL) was evaluated. Wastewater samples were collected from a rubber glove manufacturing factory with COD of 688 mg l^{-1}. Response surface methodology (RSM) with a two-variable, five-level central composite design (CCD) was employed to study and optimize the CF process using alum, ferric chloride, and poly aluminum chloride as the coagulants. The results showed that maximum COD reduction (56.06%) was obtained using alum at the optimal condition of 560 mg l^{-1} coagulant dose and pH 8.4. Fenton oxidation process was applied to the wastewater after coagulation. The process was optimized by RSM using a three-variable, three-level Box–Behnken design (BBD). Maximum COD reduction (78.26%) at this stage was obtained under treatment conditions of H_2O_2 1257 mg l^{-1}, H_2O_2/ Fe^{2+} ratio 2.31, and 76 min. Final COD of the treated effluent was 68.6 mg l^{-1}. The integrated technique consisted of CF and FO processes was proved to be efficient for the treatment of latex-containing wastewater with 90.03% COD reduction. The proposed method can be used to treat the NRL wastewater to a suitable quality for reuse in the manufacturing process.

1. Introduction

Nowadays, there is a constantly increasing worldwide concern for the development of sustainable wastewater treatment and reuse technologies. Treating wastewater for reuse is essential for water resources conservation and avoidance of environmental degradation [1]. In many countries, the high rates of water consumption in the last decade have put excessive pressure on existing water resources increasing the cost of raw water for industrial applications. Industries that consume large quantities of water and produce large volumes of wastewater have a great potential for wastewater reuse.

Rubber gloves manufacturing industries generate large volumes of wastewater with high organic load. The main raw material for the manufacture of glove is natural rubber latex (NRL) that has been the most satisfactory material because of its excellent barrier protection against microorganisms and infectious fluids. NRL, cis-1,4-polyisoprene, is a high molecular weight polymeric material, sticky milky white or slightly yellowish opaque fluid. The major commercial source of NRL is the Para rubber tree, Hevea brasiliensis, a member of the spurge family Euphorbiaceous [2]. NRL is extensively used in various products such as gloves. In addition, dry natural rubber is the raw material for the production of tires, tubing, hoses, footwear, automotive components, engineering parts, adhesives, rubber-cut thread, and some household articles [3].

Latex wastewater contains high suspended solids (the remaining latex), high organic matter and nitrogen-containing pollutants (organic N, N-NH_3), high acidity and strong smell [4]. Wastewaters containing latex are treated by different methods. Biological treatment systems, such as anaerobic-cum-facultative lagoon, anaerobic-cum-aerated lagoon, aerated lagoon, and oxidation ditch systems [5], are conventionally used for latex wastewater treatment. Chemical methods, such as coagulation [6], and physical methods, such as rock bed filtration and ultrafiltration [7,8], have been also investigated for the treatment of natural rubber wastewater. The conventional biological treatment methods have the problem of longer hydraulic retention time and are subjected to failure by shock loads. In addition, physical treatment methods encounter the fouling problems, and most of the chemical treatment technologies are only suitable for primary treatment [5]. In this study, an optimal treatment method by combining coagulation-flocculation (CF) and Fenton oxidation (FO) processes is introduced. It should be noted that, so far, there is no report on the treatment of latex-containing wastewater by combined CF-FO process.

Advanced oxidation processes (AOPs) have been used for the removal of wastewater pollution by turning the pollutants into less-toxic and readily biodegradable products [9]. AOPs have demonstrated high efficiencies in removing organic compounds [4]. Among the AOPs, the classical Fenton treatment is an extremely attractive option due to the low-operating cost and low toxicity of the reagents [10]. This method has also other advantages such as high efficiency, simplicity, low amount of residues and high potential to treat many different compounds [11]. The oxidation process consists of the reaction of Fe^{2+} salts with H_2O_2 to generate hydroxyl radical [10], the second strongest oxidizing agent after fluorine [12]. In this case, Fe^{2+} ions act as a catalyst for the formation of the •OH [13]. The Fenton's reagent has already been used for the treatment of various industrial effluents [9,14]. The efficiency of the Fenton's reaction depends mainly on Fe^{2+} and H_2O_2 concentrations [15]. Therefore, the concentrations of the Fenton's reagents should be optimized to achieve the best treatment conditions. For this purpose, response surface methodology (RSM) is a better alternative to the conventional optimization methods. RSM is a combination of statistical techniques for designing experiments, developing and analyzing models, and achieving the optimum conditions with a limited number of planned experiments [16].

The present work was aimed to evaluate the effectiveness of combined coagulation-flocculation and Fenton oxidation in the treatment of latex-containing wastewater. The treatment was performed in order to attain the quality standards appropriate to the effluent reuse in the manufacturing process (i.e. COD < 150 mg l^{-1}). Design of experiments and response surface methodology (RSM) were used to study and optimize the key operating parameters of the CF and Fenton processes.

2. Experimental details

2.1. *Sample collection and characterization*

The wastewater was collected from a natural rubber glove manufacturing factory, located at Guilan Province, Iran, generating around 700 m^3 of wastewater per day. Pretreatment of latex wastewater was performed in the factory. NRL particles were coagulated by adding calcium nitrate. The particles were floated and removed from the surface of the effluent. The samples were collected from the pretreated effluent at regular intervals and stored at 4 ◦ C before the experiments. Characteristics of the sample are presented in Table 1.

Table 1: Characteristics of the effluent before treatment with combined CF-FO process

parameter	value
pH	5.7
COD (mg l^{-1})	688
TSS (mg l^{-1})	114
DO (mg l^{-1})	83
Turbidity (FTU)	257
Conductivity (ms)	2.38

Alum ($Al_2(SO_4)_3.18H_2O$), poly aluminum chloride (PAC), $[Al_2(OH)_nCl_6 \cdot xH_2O]_m$ (m≤10, n=3~5), and ferric chloride, $FeCl_3.6H_2O$, were obtained from Merck (Darmstadt, Germany). Sulfuric acid, NaOH, and hydrogen peroxide (30% w/w) were purchased from Sigma-Aldrich. All chemicals used were of analytical grade.

COD was determined according to the Standard Methods by closed reflux titrimetric method [17].

A digital pH-meter (HACH, HQd) was used for pH measurement. Turbidity was measured by a turbidity meter (ELICO CL 52D NEPHELOMETER). Total suspended solids (TSS) was determined according to the Standard

Methods [17]. A conductivity meter (ELICO CM 180) was used to measure the conductivity. Dissolved oxygen was determined by ELICO PE 135 DO Analyser.

2.2 *Coagulation-Flocculation (CF) process*

Six 500 mL-beakers were filled with 400 mL of wastewater and placed in the slots of a jar tester (Zagchemie, Iran). The pH of samples was adjusted to the desirable values (according to the experimental design) by addition of diluted H_2SO_4 or NaOH solution. Then, three different coagulants, alum, PAC and ferric chloride, were added. The samples were rapidly stirred for 5 min at 200 rpm, and then slowly mixed for 20 min at 20 rpm [18]. Then, the solution was kept undisturbed for 30 min for sedimentation. The clarified samples were collected from the top of the beakers and filtered using filter paper to remove any remaining sediment.

2.3 *Advanced oxidation by Fenton's reaction*

After the CF stage, chemical oxidation was performed using Fenton's reagent. Initially, 500 mL of sample was put in a 1000 mL beaker and magnetically stirred; pH was adjusted to the fixed value of 3 by adding H_2SO_4. Then, the effects of operating conditions including contact time, H_2O_2 dosage, and $[H_2O_2]/[Fe^{2+}]$ ratio, on the COD reduction were evaluated. The catalyst (ferrous sulphate) was introduced after pH adjustment to avoid iron precipitation. The COD reduction percentage was obtained using the following equation:

$$\text{COD reduction (\%)} = \text{CODi-COD}_f / \text{COD}_i \qquad (1)$$

where COD_i and COD_f are the values before and after the CF process, respectively.

2.4 *Experimental design, analysis and optimization*

Experimental design, analysis and optimization were performed with the Design Expert (Stat-Ease, MN, USA) software, version 6.0.6. For the CF process, a two-variable, five-level Central Composite Design (CCD) were employed to optimize the two independent parameters: initial pH (A) and coagulant dose (B). The range of the variables were determined by preliminary experiments as coagulant dosage 200-800 mg l^{-1}, and pH 6–10 for alum; coagulant dosage 200-1000 mg l^{-1}, and pH 9-11 for PAC; and coagulant dosage 150-750 mg l^{-1}, and pH 5-8 for ferric chloride. The CCD comprised of 4 factorial points, 4 axial points and 2 center points. The design of experiments employed and the percentages of COD reduction as the response are presented in Table 2. Analysis of variance (ANOVA) was used to determine whether the developed model was statistically significant (Table 3). Modeling and optimization of the Fenton oxidation process was performed by a Box–Behnken design (BBD) with three independent factors, dose of H_2O_2 (A), $[H_2O_2]/ [Fe^{2+}]$ (B) and reaction time (C). The employed experimental design and the corresponding responses are presented in Table 4. The ANOVA was used to check the adequacy of the model.

3. Results and Discussion

3.1. Statistical analysis and optimization of the CF process

The CCD design employed for analysis of the CF process is presented in Table 2. Fitting of the experimental data to the full quadratic multiple regression model and the subsequent ANOVA showed that COD reduction by alum could suitably described by the following equation:

$$\text{COD reduction (\%) by alum} = +55.12 +3.44\,A +6.67\,B -8.67\,A^2 -15.62\,B^2 -2.84\,AB \qquad (2)$$

where A is pH and B the alum concentration (mg l^{-1}).

The ANOVA for the model is shown in Table 3. The F-value of the model (69.27) with a p-value less than 0.05 implies that the model is significant at the 95% confidence level. The model showed no lack of fit (LOF) at the 95% level of significance. A very high coefficient of determination ($R^2= 0.9886$) also indicates the adequacy of the model for representing the real relationship among the parameters.

Equation 3 represents the relationship between COD reduction by PAC and the CF process parameters:

$$\text{COD reduction (\%) by PAC} = +40.00 +4.50\,A +5.79\,B -7.00\,A^2 -9.61\,B^2 +1.57AB \qquad (3)$$

where A is pH and B the PAC concentration (mgL^{-1}).

Table 2: Composition of various experiments of the CCD design for the CF process

	Alum			**PAC**			**$FeCl_3.6H_2O$**		
Run	Variable		COD reduction (%)	Variable		COD reduction (%)	Variable		COD reduction (%)
	pH	Coagulant dose (mg l^{-1})		pH	Coagulant dose (mg l^{-1})		pH	Coagulant dose (mg l^{-1})	
1	6.0	200.0	18.65	7.0	200.0	18.65	5.0	150.0	25.76
2	6.0	800.0	35.87	7.0	1000.0	26.65	5.0	750.0	31.54
3	5.2	500.0	32.76	5.8	600.0	11.43	4.2	450.0	21.87
4	10.0	800.0	35.63	11.0	1000.0	35.65	8.0	750.0	23.58
5	8.0	924.3	35.45	9.0	1109.4	29.43	6.5	832.0	32.54
6	10.8	500.0	44.52	12.2	600.0	29.69	8.8	450.0	17.65
7	8.0	75.7	14.02	9.0	90.6	13.98	6.5	67.9	15.71
8	10.0	200.0	29.76	11.0	200.0	21.38	8.0	150.0	12.56
9	8.0	500.0	56.17	9.0	600.0	41.56	6.5	450.0	45.41
10	8.0	500.0	54.07	9.0	600.0	38.54	6.5	450.0	47.54

The ANOVA for the model is presented in Table 3. The model p-value of 0.0179 shows that the model is significant at the 95% confidence level. In addition, the LOF of the model is not significant relative to the pure error. A high coefficient of determination (R^2= 0.9338) also shows that the regression model fits the data well. The COD reduction percentage using $FeCl_3$ can be explained by the following equation:

$$\text{COD reduction (\%) by } FeCl_3 = +46.39 - 3.18\,A + 5.28\,B - 10.98\,A^2 - 13.01\,B^2 + 1.31\,AB \quad (4)$$

According to ANOVA (Table 3), only coagulant ($FeCl_3$) dose has a significant effect on the COD reduction. The developed model is significant with an F-value of 18.24 and a p-value less than 0.05. The LOF of the model (7.53) is not significant relative to the pure error. There is a 26.03% chance that a lack of fit F-value this large could occur due to noise. The high R^2, 0.9580, also indicates a good agreement between the model predicted and the experimental values.

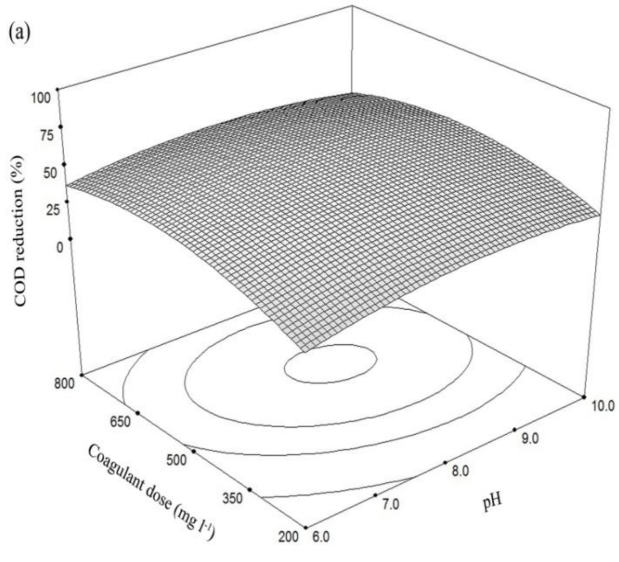

Figure 1: Response surface plots showing the interaction between two parameters, pH and coagulant dose on the COD reduction by CF process using alum.

The developed models could be used to navigate the design space defined by the CCD. The three-dimensional (3D) response surface plot showing the interaction effects of pH and coagulant dose on the COD reduction for alum is presented in Figure 1. Similar trend was observed for PAC and $FeCl_3$.

Table 3: ANOVA for the models used for the effluent treatment by various coagulants

Source	Sum of squares	Degree of freedom	Mean square	F-value	P-value
Alum					
Model	1620.31	5	324.06	69.27	0.0006
A	94.5391	1	94.5391	20.21	0.0109
B	356.399	1	356.399	76.19	0.0009
A^2	343.43	1	343.43	73.42	0.0010
B^2	1115.36	1	1115.36	238.44	0.0001
AB	32.2056	1	32.2056	6.88	0.0586
Total error	18.7113	4	4.67		
Note: R^2 = 0.9886; p-value of LOF = 0.4283					
PAC					
Model	882.95	5	176.59	11.28	0.0179
A	183.48	1	183.48	11.72	0.0267
B	242.89	1	242.89	15.51	0.0170
A^2	340.57	1	340.57	21.75	0.0096
B^2	300.06	1	300.06	19.16	0.0119
AB	9.83	1	9.83	0.63	0.4725
Total error	62.63	4	15.66		
Note: R^2 = 0.9338; p-value of LOF= 0.3394					
$FeCl_3$					
Model	1219.84	5	243.97	18.24	0.0074
A	87.73	1	87.73	6.56	0.0626
B	201.80	1	201.80	15.09	0.0178
A^2	743.16	1	743.16	55.56	0.0017
B^2	558.95	1	558.95	41.79	0.0029
AB	6.86	1	6.86	0.51	0.5134
Total error	53.51	4	13.38		
Note: R^2 = 0.9580; p-value of LOF= 0.2603					

Finding the optimal amount of coagulant is necessary in order to minimize the dosing cost as well as sludge formation. The results show that, for all coagulants investigated, by increasing the coagulant dose up to an optimum value, COD reduction is increased. Further increase in the amount of coagulants leads to decrease in the COD reduction percentage. In fact, insufficient dosage or overdosing of coagulant results in the poor performance of CF process [19]. Overdosing would result in complete charge reversal, restabilization of colloids and decrease in the sedimentation rate. In addition, coagulant overdosing would lead to excessive sludge production and need for more chemicals for pH and corrosion control. On the other hand, an under-dose of coagulant is not sufficient to neutralize the negative charge of the colloid surface [20].

The initial pH of the effluent has a remarkable effect on COD reduction in CF process [21]. At varying pH values, the amount of ions being formed in solution may be less than optimum. A low pH may not allow the coagulation process to proceed, while high pH can cause a coagulated particle to redisperse. The size of the coagulated particles is also affected by pH, which determines the density of the flocs and rate of settling. The optimum pH of coagulation not only depends on the coagulant type but also on the nature of wastewater [22]. The mechanism of CF process is different under different pH conditions. At low pH, anionic dissolved organic molecules interact with metal cations and form insoluble metal complexes while at high pH and high coagulant doses, the organic molecules adsorb onto metal hydroxide flocs and precipitate [22]. According to Figure 1, for all coagulants, at lower pH values, COD reduction was lower and it increased to maximum value at the optimum pH, after which there was another fall off in COD reduction efficiency at higher pH values.

By using the desirability function analysis, RSM can predict the optimum combination of parameters to obtain the highest percentage of COD reduction. The optimal condition of the CF process using alum was found as the coagulant dose of 560.34 mg l^{-1} and pH 8.4. Under this optimum condition, maximum COD reduction was estimated to be 56.06%. The optimal condition for coagulation by PAC was pH 9.7 and 718 mg l^{-1} coagulant dose yielding 41.62% COD reduction.

Maximum COD reduction (47.25%) by $FeCl_3$ was predicted at pH 5.7 using coagulant dose of 552.15 mg l^{-1}. Iron salts have maximum coagulation efficiency under acidic conditions. Although the cost of iron compounds may often be less than that of alum, the iron compounds are generally corrosive and their use may result in high soluble iron concentration in process effluents [22]. Furthermore, ferric chloride has a lower efficiency for removing organic suspended solids than alum. This result was observed by Jar test studies.
The results showed that the highest COD reduction percentage was obtained using alum as the coagulant.

3.2. Statistical analysis and optimization of the Fenton oxidation process

Due to the inadequate COD reduction in the CF stage, further treatment of the wastewater was performed using the Fenton's reagent. Response surface methodology (RSM) with a three-variable, three-level Box–Behnken design (BBD) was used to study and optimize the oxidation process. The variables and their levels selected for the Fenton oxidation process were H_2O_2 concentration (100-2000 mg l^{-1}), H_2O_2/ Fe^{2+} (0.5-3), and time (10–120 min). COD reduction at the oxidation stage was analyzed as the response. Ranges of the variables (H_2O_2 concentration, and H_2O_2/ Fe^{2+} ratio) were selected based on the stoichiometric hydrogen peroxide requirement for COD reduction. The BBD employed is presented in Table 4.

Table 4: Composition of various experiments of the BBD design for the Fenton oxidation process

Run	Factor			COD reduction (%)	
	$[H_2O_2]$ (mg l^{-1})	$[H_2O_2]$/ $[Fe^{2+}]$	Time (min)	Actual value	Predicted value
1	1050	0.5	10	22.25	18.8963
2	100	3	65	23.65	24.7388
3	1050	3	10	48.54	47.1013
4	1050	1.75	65	72.38	72.55
5	100	1.75	10	11.88	12.23
6	1050	1.75	65	71.02	72.55
7	2000	1.75	10	24.72	29.1625
8	100	1.75	120	25.78	21.3375
9	1050	3	120	55.87	59.2237
10	1050	0.5	120	30.66	32.0988
11	2000	1.75	120	45.73	45.38
12	2000	3	65	58.98	55.9762
13	1050	1.75	65	74.25	72.55
14	2000	0.5	65	18.65	17.56
15	100	0.5	65	4.82	7.82375

Fitting of the data to the full quadratic multiple regression model and the subsequent ANOVA showed that COD reduction by the FO process could suitably described by the following equation:

$$\text{COD reduction (\%)} = +72.55 +10.24\,A+13.83\,B +6.33\,C -29.16A^2 -16.86\,B^2 -16.36\,C^2 +5.38\,AB +1.78\,AC-0.27\,BC \qquad (5)$$

where A is hydrogen peroxide concentration, B H_2O_2/ Fe^{2+} ratio, and C the time.
The ANOVA for the model is presented in Table 5. The F-value of the model (44.62) with a p-value less than 0.05 implies that the model is statistically significant at the 95% confidence level. The LOF of the model (0.0845) is not significant relative to the pure error. The very high coefficient of determination (R^2= 0.9877) also indicate a good agreement between the model predicted and the experimental values [23].
The Fenton's reaction has two distinct stages: oxidation which is based on the formation of hydroxyl radicals and coagulation which is mainly simple ferric coagulation [24]. The mechanism of Fenton's reaction has been described as:

$$H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + OH^{-} + OH^{\bullet} \qquad (6)$$
$$OH^{\bullet} + RH \rightarrow H_2O + R^{\bullet} \qquad (7)$$
$$R^{\bullet} + Fe^{3+} \rightarrow R^{+} + Fe^{2+} \qquad (8)$$
$$R^{+} + H_2O \rightarrow ROH + H^{+} \qquad (9)$$

The hydroxyl radical generated would attack the organic substrate, RH [25].

Fenton process has a typically sharp, preferred pH region in which it is optimally operated. The pH affects the activity of the oxidant and catalyst, the speciation of iron, and hydrogen peroxide decomposition [26]. According to the literature on the oxidation of organic compounds in wastewater, pH was adjusted to the fixed value of 3 [27].

Table 5: ANOVA for the model used for the analysis of the Fenton oxidation process

Source	Sum of squares	Degree of freedom	Mean square	F-value	p-value
A	839.475	1	839.475	45.61	0.0011
B	1530.7	1	1530.7	83.17	0.0003
C	320.678	1	320.678	17.42	0.0087
A^2	3140.4	1	3140.4	170.62	0.0000
B^2	1049.73	1	1049.73	57.03	0.0006
C^2	988.094	1	988.094	53.68	0.0007
AB	115.563	1	115.563	6.28	0.0541
AC	12.638	1	12.638	0.69	0.4450
BC	0.2916	1	0.2916	0.02	0.9047
Total error	92.0275	5	18.4055		

Note: $R^2 = 0.9877$; LOF p-value = 0.0845

It is supported by several studies that the H_2O_2/Fe^{2+} ratio is the key parameter for improving the efficiency of the Fenton's reaction [25]. In this study, according to the ANOVA, H_2O_2/Fe^{2+} ratio was also found to be the most significant parameter in the Fenton's oxidation process. Both H_2O_2 and Fe^{2+} can react with hydroxyl radicals and reduce the amount of radicals available to substrates [28]. Therefore, optimum H_2O_2/Fe^{2+} ratio must be determined to achieve the maximum COD reduction. Figure 2 presents the response surface plot in a 3D representation reflecting the effects of H_2O_2/Fe^{2+} and H_2O_2 concentration on the COD reduction of latex wastewater.

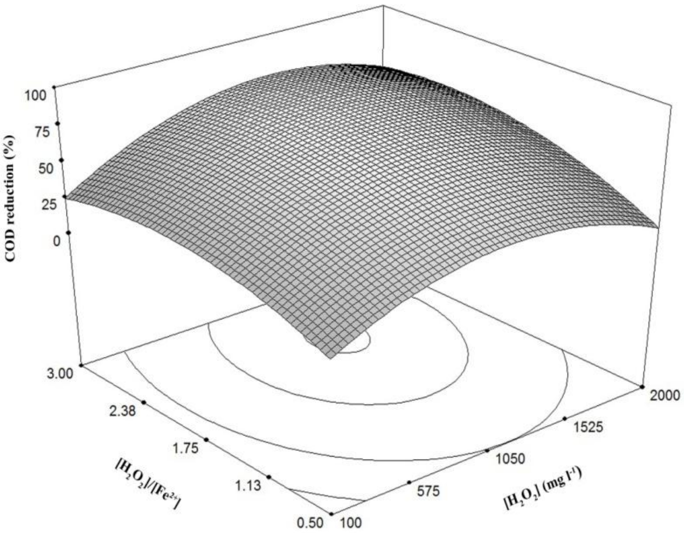

Figure 2: Response surface plots showing the interaction between two parameters, H_2O_2/Fe^{2+} ratio and H_2O_2 concentration on the COD reduction by Fenton oxidation.

It can be seen that COD reduction increased as the H_2O_2/Fe^{2+} ratio increased to 2.31 and thereafter decreased with further increase to 3.00. The optimum H_2O_2/Fe^{2+} ratio depends greatly on the types of organics as well as their loads [25]. By increasing H_2O_2 concentration from 100 to 1257 mg l^{-1}, COD reduction increased, and then a decrease in the removal efficiency was observed by increasing H_2O_2 concentration to 2000 mg l^{-1}. When the H_2O_2 concentration exceeds the optimal value, its decomposition decreases due to the scavenging effect and regeneration of H_2O_2 (Eq. 10) [29]:

$$H_2O_2 + OH^\bullet \rightarrow HOO^\bullet + H_2O \qquad (10)$$

$$HOO^{\bullet} + HOO^{\bullet} \rightarrow H_2O_2 + O_2 \qquad (11)$$

$$OH^{\bullet} + OH^{\bullet} \rightarrow H_2O_2 \qquad (12)$$

It should be noted that since the main chemical cost of Fenton reagent is the cost of H_2O_2, optimization of the H_2O_2 concentration in the process is very important [29].

The effect of varying time and H_2O_2 concentration is shown in Figure 3. Figure 4 depicts the 3D response surface plot regarding the effect of time, H_2O_2/ Fe^{2+} ratio, and their interactions on the COD reduction at H_2O_2 concentration of 1050 mg l^{-1} (center point of the experimental design). Reaction time is an important parameter in Fenton process. Optimum reaction time for Fenton process depends on the type of wastewater and catalyst dosage. Various reaction times ranging from 30 min to 3 h have been reported in the literature [30]. The results showed that optimum time for maximum COD reduction in this stage was 76 min.

The optimal conditions for the FO process were determined using the desirability function analysis. The maximum COD reduction (77.40%) was predicted under treatment conditions of H_2O_2 1257 mg l^{-1}, H_2O_2/ Fe^{2+} 2.31, and 76 min. The actual experimental value obtained was 78.26% with 0.86% deviation. According to the results, by combination of CF and FO processes, 90.03% COD reduction was achieved. Final COD of the treated effluent after the second stage was 68.6 mg l^{-1} (< 150 mg l^{-1}), which made it suitable for reuse in the manufacturing process.

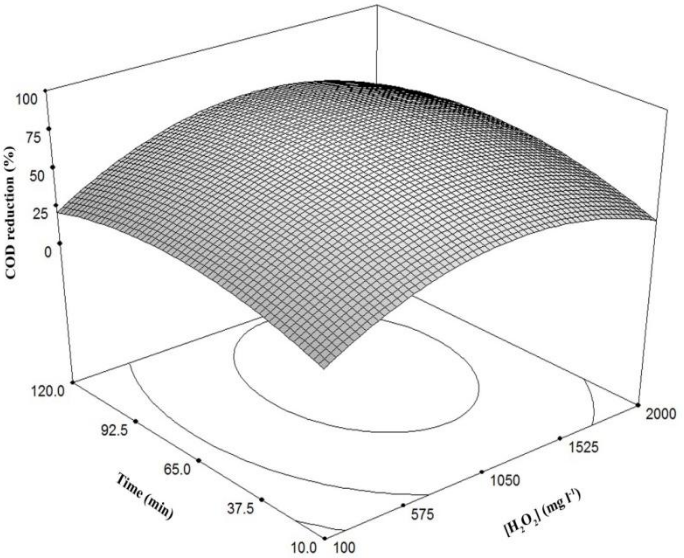

Figure 3: Response surface plots showing the interaction between two parameters, time and H_2O_2 concentration on the COD reduction by Fenton oxidation.

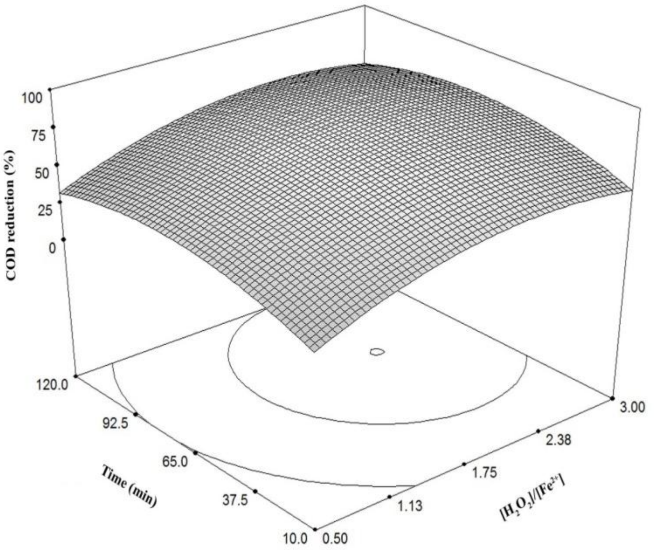

Figure 4: Response surface plots showing the interaction between two parameters, time and H_2O_2/Fe^{2+} ratio on the COD reduction by Fenton oxidation.

Conclusions

Coagulation-flocculation and Fenton oxidation processes were successfully implemented for the treatment of latex-containing wastewater. Response surface methodology was effectively applied to the modeling and optimization of both processes. For the CF process, alum was found to be more efficient than ferric chloride and PAC. Up to 56% COD reduction was obtained at pH 8.4 using 560.34 mg l^{-1} of alum. When coagulation was coupled to Fenton oxidation under optimal conditions of H_2O_2 1257 mg l^{-1}, H_2O_2/ Fe^{2+} 2.31, and 76 min, 90% COD reduction was achieved. The treated effluent was suitable for reuse in the manufacturing process. The proposed treatment technique would minimize environmental pollution of natural rubber industry and overcome the problems of conventional systems.

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