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Treatment of hospital wastewater by potassium ferrate

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ABSTRACT

It has been investigated how well potassium ferrate (K2FeO4) treats hospital wastewater effluents. In the treatment of water and wastewater, potassium ferrate serves as an oxidant, disinfectant, and coagulant with several functions. The effects of combining the oxidation and coagulation processes on features have not been extensively studied. The objective of this study is to evaluate the oxidation and coagulation effects of potassium ferrate treatment methods. An optimization technique based on Response Surface Methodology (RSM) and Box-Behnken Design(BBD) was utilized to identify the ideal conditions for increased removal efficiency of Chemical Oxygen Demand (COD). Potassium ferrate has a significant impact, according to experiments. With a COD of 790 ppm as the starting point, the effects of oxidation time (30-90 minutes), potassium ferrate concentration (20-100 ppm), pH (3-9), and process stirring speed (100-400 rpm) on COD removal efficiency were examined. To find the best COD removal efficiency, it also used an optimization strategy based on the Box-Behnken design via the Response Surface Method (RSM). According to the findings, time, mixing speed, and pH are the factors that have the highest impact on the effectiveness of COD removal. Based on the study of the Minitab-19 program, Regression analysis results revealed a Fisher value of 13.68. pH value 3, oxidation time of 62 minutes, mixing speed of 300 rpm, and potassium ferrate content of 92 ppm was discovered to be the optimal operating parameters. Based on this ideal scenario, the final concentration reached had a COD elimination effectiveness of 98 percent.

1. Introduction

Recent years have seen an increase in the study of how prescription medications affect the aquatic environment as a result of industry, medical facility, and household wastewater discharges [1-3]. Long-term effects on individuals and ecosystems are difficult to predict due to a lack of understanding of the sustainable effects of exposure to very low concentrations , bioaccumulation, teamwork, or the aggregate of several molecules. However, it is still challenging for international water companies to find ways to dispose of them. contaminants because of concerns about their potential for negative effects. Utilizing activated sludge and subsequent sedimentation, approximately 80 % of the total pharmaceutical load pass through the treatment vegetation[4]. Many physical, organic, and chemical strategies were explored and reviewed [5] because the conventional wastewater remediation method isn't always effective in getting rid of

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Nomenclature		FTIR	Fourier Transform-Infra Red
BBD	Box–Behnken Design	XRD	X-Ray Diffraction
COD	Chemical Oxygen Demand	CI	Confidence interval
X1	Potassium ferrate concentration ppm	DOF	Degree Of Freedom
X2	mixing speed rpm	D	Desirability function
X3	oxidation time (min)	Seq.SS	Sum Of Square
X4	pH		
x1	value tagged for COD	Adj. SS	Adjusted Sum of Square
x2	speed coded value	Adj. MS	Adjusted Mean of Square
x3	time value coding	adj. R2	Adjusted Coefficient of Multiple Correlation
x4	pH value coding	predR2	Predicted Multiple Correlation Coefficient
ao	The intercept code	N	Number of runs
ai	The superior (linear) significant impact	K	Number of processing parameters
aii	major second-class impact	Y	Represents the dependent variable (RE)
aij	The impact of interaction	SE	Standard Error of Regression
		S	Standard error of mean

prescription medicines. Iron-based material ferrate (VI) (FeO42), one of the many oxidants used in the wastewater treatment industry, has proven to be effective at removing a great variety of prescription medications, including antibiotics, lipid regulators, antipyretics, anticonvulsants and betabloquants [6,7].With redox capability, ranging from 0.72 V in alkaline media (pH = 14) to 2.20 V below barely acidic conditions (pH = 0), Fe(VI) well-known exhibits several advantages. It acts primarily as an oxidizer and disinfectant for the entire pH range. It is subsequently converted to the coagulant ferric hydroxide, Fe(OH)3, which is non-poisonous. nine Due to its ability to oxidize, disinfect, coagulate, and precipitate pollutants both naturally occurring and inorganically[9–11], Fe(VI) appears to be effective. Fe(VI) has many benefits compared to other commonly used oxidizers such as chlorine, chlorine dioxide, permanganate, hydrogen peroxide, and ozone., including its versatility and environmental friendliness[12]. The use of potassium ferrate(VI) as a chemical reagent for wastewater treatment has been extensively reviewed by a number of authors.The use of ferrate(VI) to oxidize a variety of synthetic organic molecules, including alcohol [14] and carboxylic compounds [15]. Iron (VI) compounds may be utilized as inhibitory additives since the degree of corrosion prevention reached 60%[18]. It can be used as a multifunctional chemical for the treatment of water and wastewater and is a substantial substitute for advanced oxidation techniques (AOP)[19].

2. Materials and method

2.1. The chemical oxygen demand (COD)

The measurement of organic strength in domestic and commercial waste waters has been thoroughly defined with relation to COD. It is based on the fact that the majority of organic molecules can be oxidized by potent oxidizing agents in acidic conditions. The quick turnaround time is the primary benefit of COD measurements. Instead of the five days required by BOD, tests might be finished in three hours. Therefore, COD may be utilized rather than the BOD test [16]. The amount of COD was determined using a sample (2 ml) from the effluent digested with potassium dichromate conducted at room temperature. The following formula was used to compute the COD removal efficiency (R percent) using COD (Eq. 1) (K2Cr2O7) for 120 minutes at 150 C in a COD thermoreactor. Average values were used to analyze the data as:

$$R\% = (C_0 - C) / C_0 * 100 \tag{1}$$

Where C_0 is the initial concentration of the cod removal and C is the final concentration of the cod removal.

2.2. Turbidity measurements

After each run, pipet the sample from the beakers into the tube, making sure there are no air bubbles in the HWW sample. Take into account reading the test sample after it has been placed in a turbid meter that has been calibrated.

2.3 Design of experiments

To fit the model of any response and identify the ideal operating parameters for this response, a group of statistical and mathematical approaches outlined by Minitab-19 Software can be employed. The Box Bhenken design was employed in this work to improve and ascertain the effect of factors like pH and the addition of potassium ferrate on the effectiveness of COD removal by oxidation.Response optimization in Minitab-19 Software can be done in a variety of methods. In order to confirm and contrast variables that affected COD removal from HWW, this study used Box-Behnken empirical designs with three tiers and four components. Potassium ferrate concenteration (X1), mixing speed (X2), oxidation duration (X3), and pH value (X4) were the process variables, and COD elimination efficiency was the outcome. Using the middle or center point (0), -1 (low level), and +1, the scale of process variables was coded (high level). The equation below can be used to resolve Box–Behnken designs and build the necessary quadratic model with the necessary statistical qualities using the runs needed for a 3-level factorial.

$$N = 2k\,(k-1) + cp \tag{2}$$

where cp is the central point's repeated number and k represents the number of processing parameters. As part of this work, 27 trials were performed to assess the impact of process factors on the removal efficiency of COD. The Box–Behnken Design (BBD) suggested for the current study is illustrated in Table 2. Based on BBD, the following equation [3] can be used to characterize how the interaction terms correspond to the test data. in a second order polynomial model:

Table 1. Process variables and their impact on the elimination of COD

Process parameters	range in Box–Behnken design		
Coded levels	**Low(-1)**	**Middle(0)**	**High (+1)**
X_1- Initial conc. (ppm)	20	60	100
X_2- mixing speed (rpm)	100	250	400
X_3- oxidation time(min)	30	60	90
X_4-pH value	3	6	9

$$Y= a_0+ \sum a_i\ x_i+ \sum a_{ii}\ x_i^2+ \sum a_{ij}\, x_i\, x_j \qquad (3)$$

The method variables (independent variables) are represented by the coded form of X, where Y stands for the variable (RE), I and j are the pattern index numbers, a0 is the intercept term, and x1, x2,..., xk are the method variables. First-order (linear) effects are the main effects of AI, while second-order and interaction effects are the main effects of AII and AIJ, respectively. Following the analysis of variance, the parametric sstatistics (R2) were calculated to assess the precision of the model fit.

3. Results and discussion

3.1 Potassium ferrate characteristics

FTIR, SEM, and XRD were utilized by the researchers to describe potassium ferrate. To determine chemical bonds in molecules, FTIR is utilized. When potassium ferrate is in powder form, SEM is utilized to capture structural images and micrographs. XRD It is an illustration of the analytical methods employed to validate the crystal structures and crystallinity of potassium ferrate.

3.2 Statistical analysis

For the purpose of maximizing the assembly of a specific material, statistical techniques like RSM are utilized to optimize operational parameters. The determination of the interaction between process components employs statistical tools rather than conventional techniques. In 27 tests, using a variety of process factors in separate groups, suppression ratios and knowledge of optimization between them were examined to see how they evolved.Table 3 shows the removal values for each experiment. ANOVA variance analysis, which is a statistical technique that divides the total variation in a large group of data into distinct portions given certain causes of variation, was employed to evaluate hypotheses regarding the model coefficients[12,13]. The Fisher F-test and P-test were used to determine whether an ANOVA is adequate. The high value of F shows that the regression equation accounts for the majority of the variation in the result. To determine whether F is large enough to indicate statistical significance, the accompanying P-value is used. The chosen model was able to explain 95.10 percent of the variability with a P-value of 0.00[16]. The response surface quadratic model's ANOVA was displayed in Table 4. The square sum (SeqSS), degree of freedom (DF), adjusted sum of squares (Adj SS), and adjusted mean of square were shown in this table (Adj MS).

At P equal to 0.00 percent contribution from each parameter, F-value, and P-value, the value of F is equal to 13.68 at P. It demonstrates how important the regression model is. A quadratic model of the Removal Efficiency of COD (RE) was created in terms of encoded units for process variables, and the results of the COD removal efficiency were investigated using the Minitab-19 program as a pilot

$$\text{COD RE\%} = 79.80 + 0.1225\ x_1+ 0.0604\ x_2+ 0.0892\ x_3- 0.409\ x_4- 0.000894\ x_1^2- 0.000049\ x_2^2\ - 0.000667\ x_3^2+ 0.0042\ x_4^2 + 0.000072\ x_1x_2- 0.000208\ x_1x_3+ 0.00917\ x_1x_4\ - 0.000040\ x_2x_3- 0.00493\ x_2x_4 + 0.00994\ x_3x_4 \qquad \mathbf{(4)}$$

Table 2 . Using the box-behnken experimental design

		Coded value							
Run	**Blocks**	**X_1**	**X_2**	**X_3**	**X_4**	**Initial conc. (ppm)**	**Speed (rpm)**	**Time (min)**	**pH**
1	1	1	0	0	-1	60	250	90	3
2	1	1	1	0	0	100	100	60	6
3	1	0	1	-1	0	60	400	60	9
4	1	0	0	0	0	60	400	60	3
5	1	-1	0	-1	0	60	100	90	6
6	1	-1	0	0	-1	20	400	60	6
7	1	0	-1	-1	0	60	250	60	6
8	1	0	-1	0	-1	60	250	60	6
9	1	0	1	0	-1	60	250	30	9
10	1	0	0	1	1	60	400	90	6
11	1	-1	1	0	0	60	400	30	6
12	1	1	-1	0	0	60	250	60	6
13	1	0	1	1	0	60	250	30	3
14	1	0	0	0	0	60	100	60	3
15	1	0	0	-1	1	60	100	30	6
16	1	-1	0	0	1	20	250	90	6
17	1	0	1	0	1	20	250	60	9
18	1	-1	-1	0	0	20	100	60	6
19	1	1	0	1	0	100	250	30	6
20	1	0	-1	0	1	100	250	90	6
21	1	1	0	0	1	100	250	60	3
22	1	1	0	-1	0	20	250	30	6
23	1	0	0	0	0	60	100	60	9
24	1	0	0	-1	-1	100	400	60	6
25	1	0	-1	1	0	100	250	60	9
26	1	0	0	1	-1	60	250	90	9
27	1	-1	0	1	0	20	250	60	3

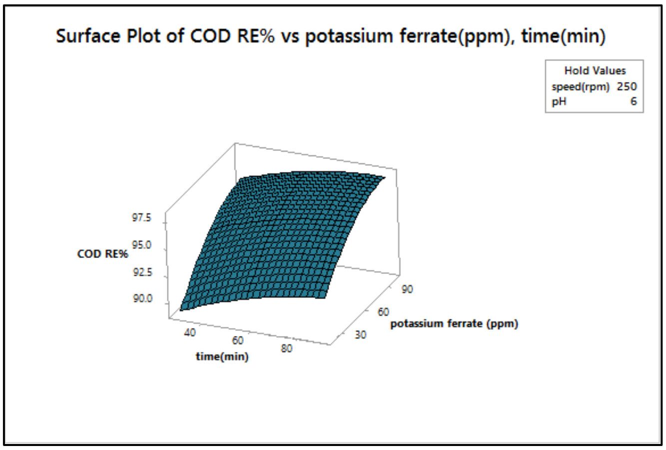
Table 3 experimental outcomes for the COD elimination using the "Box–Behnken design

Run	Blocks	Potassium ferrate (ppm)	Speed (rpm)	Time(min)	pH	RE%	
						Actual	Predict
1	1	60	250	90	3	98.00	97.1158
2	1	100	100	60	6	95.00	94.6642
3	1	60	400	60	9	93.00	92.4733
4	1	60	400	60	3	98.88	99.5900
5	1	60	100	90	6	93.00	94.4692
6	1	20	400	60	6	91.00	91.1075
7	1	60	250	60	6	96.58	95.8433
8	1	60	250	60	6	95.95	95.8433
9	1	60	250	30	9	91.00	91.6558
10	1	60	400	90	6	96.83	96.6058
11	1	60	400	30	6	94.55	94.1825
12	1	60	250	60	6	95.00	95.8433
13	1	60	250	30	3	96.58	96.1225
14	1	60	100	60	3	93.00	92.6533
15	1	60	100	30	6	90.00	91.3258
16	1	20	250	90	6	93.00	92.4283
17	1	20	250	60	9	88.00	88.9858
18	1	20	100	60	6	90.00	89.4708
19	1	100	250	30	6	96.00	95.6983
20	1	100	250	90	6	98.00	97.9817
21	1	100	250	60	3	97.60	97.7158
22	1	20	250	30	6	90.00	89.1450
23	1	60	100	60	9	96.00	94.4167
24	1	100	400	60	6	97.72	98.0208
25	1	100	250	60	9	97.00	97.2392
26	1	60	250	90	9	96.00	96.2292
27	1	20	250	60	3	93.00	93.8625

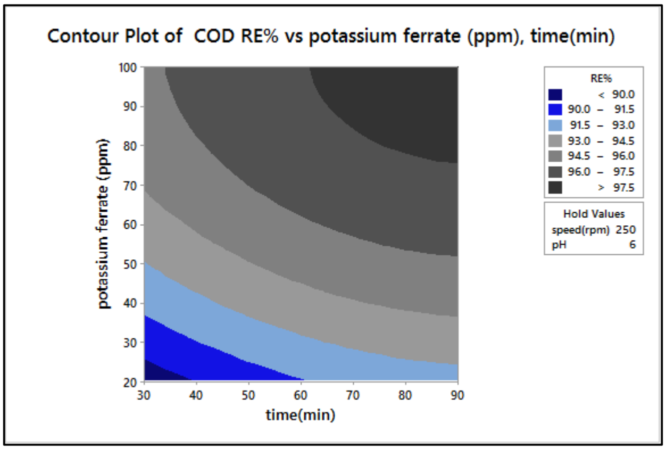
Equation (4) depicts the interaction of the factors and removal efficiency (squared and linear). According to the laboratory scale, increasing efficiency values increase with increasing positive coefficient values, whereas removal efficiency decreases with increasing negative coefficient values. It was discovered that the amount of COD and pH have a positive correlation with increasing efficiency values.

3.3 Impact of process factores on the effectiveness of COD removal

Fig. (1-a, 1-b) shows the relationship between potassium ferrate concentration and removal efficiency for various contact times (40, 60, and 80 minutes) and potassium ferrate concentrations (30, 60, and 90 ppm) at pH 6 at 250 rpm. Fig. 1-a displays the response surface plot and figure 1-b displays the associated contour plot.



(a)



(b)

Figure 2: Response surface (a) and contour plot (b) demonstrating the impact of pH and time on the effectiveness of COD removal

The surface plot clearly shows that a decline in removal efficiency occurs throughout a contact time of 40 minutes as the concentration increases. As the 90-minute contact time approached. The effectiveness of elimination changed. Additionally, at a concentration of 90 ppm, the data demonstrate that COD removal effectiveness increases with increasing contact time and potassium ferrate concentration.

Figures 2a and 2b show the impact of pH on the effectiveness of COD removal at various pH values (4, 6, and 8), at a speed of 250 rpm, and with a concentrated dose of 60 ppm. The response surface plot (2a) demonstrates that the effectiveness of COD removal is currently marginally impacted by increasing pH. The related contour piece (2-b) demonstrates that a very small area has the highest COD elimination efficiency value; its pH value was 9. The study, [16,17] demonstrated this.

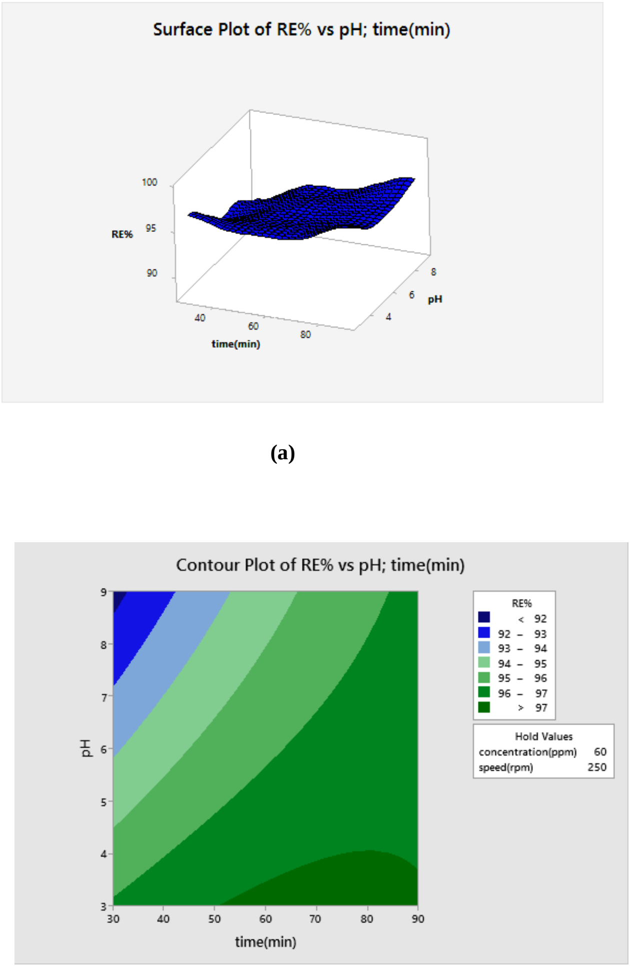
When the speed was between (100, 200, 300, and 400 rpm) at a potassium ferrate concentration of (30, 60, and 90) ppm, forms (3-a, 3-b) show the link between the speed and the concentration of potassium ferrate and its effect on the removal rate. The removal efficiency of COD increases as the focus increases, which is evident from the response surface plot (3-a), which shows that it has a substantial impact on COD removal efficiency as speed increases at 400 rpm. The accompanying contour plot (3-b) reveals that the COD removal efficiency's maximum value is located in a narrow region with speeds between 330 and 400 rpm and potassium ferrate concentrations between 97 and 100 ppm

Table 4. Variance analysis for COD reduction

Source	**DF**	**SeqSS**	**Adj MS**	**F-value**	**P-value**
1-Model	14	218.396	15.600	13.68	0.000
Linear	4	173.363	43.341	38.02	0.000
X1	1	109.929	109.929	96.43	0.000
X2	1	18.700	18.700	16.40	0.002
X3	1	23.241	23.241	20.39	0.001
X4	1	21.494	21.494	18.85	0.001
Square	4	16.156	4.039	3.54	0.039
$X1^2$	1	8.037	10.906	9.57	0.009
$X2^2$	1	5.860	6.424	5.64	0.035
$X3^2$	1	2.251	1.920	1.68	0.219
$X4^2$	1	0.007	0.007	0.01	0.937
2-Way Interaction	6	28.877	4.813	4.22	0.016
X1*X2	1	0.740	0.740	0.65	0.436
X1*X3	1	0.250	0.250	0.22	0.648
X1*X4	1	4.840	4.840	4.25	0.062
X2*X3	1	0.130	0.130	0.11	0.742
X2*X4	1	19.714	19.714	17.29	0.001
X3*X4	1	3.204	3.204	2.81	0.119
Error	12	13.680	1.140	0000	0000
Lack-of-Fit	10	12.414	1.241	1.96	0.384
Pure Error	2	1.265	0.633	0000	0000
Total	26	232.075	0000	0000	0000
Model Summary	1.06769	94.11%	87.23%	67.96%	

3.3 The confirmation and optimization test

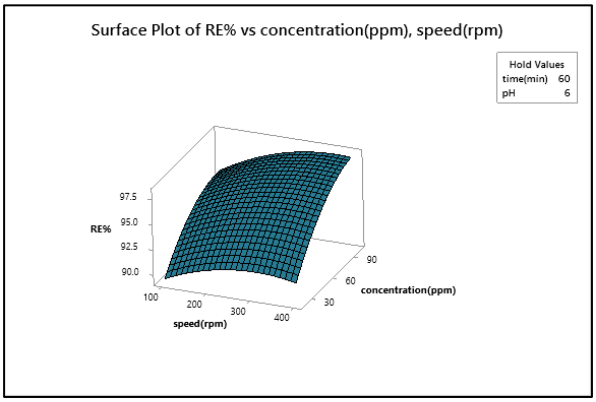
To find the precise position that maximized the Desirability Function, numerical optimization of the software is used (DF). By changing the weight or importance that may alter the qualities of the aim, the ideal goal was selected. Maximum, Minimum, Target, Within Range, and None were the five choices for the aim fields for responses. The maximum field with the corresponding 'weight'1.0 was chosen because the goal of the current effort is to achieve higher COD removal efficiency. The lower limit for the removal efficiency was set at 88 percent, and the top limit was set at 100 percent.



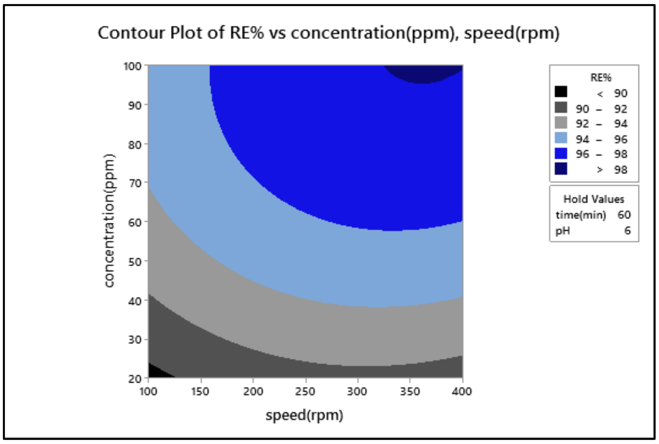
(a)

(b)

Figure 1: Response surface plot (a) and contour plot (b) illustrating the impact of contact duration and potassium ferrate concentration on the effectiveness of COD removal



(a)



(b)

Figure 3: Response surface plot (a) and contour plot (b) demonstrating the impact of potassium ferrate concentration and speed on the effectiveness of COD removal

Table 5. The optimal values for maximum COD RE%

Response	Goal	Lower	Target	Upper	Weight	Importance
RE%	Maximum	88	98.88	100	1	1

Response	Fit	SE Fit	95% CI	95% PI
RE%	100.57	1.07	(98.23, 102.90)	(97.27, 103.86)

4. Conclusions

It has been proven that employing potassium ferrate as an oxidant material allows for the successful elimination of chemical oxygen demand from a simulated wastewater solution. The RMS methodology is efficiently used to enhance process variables and determine the ideal values of these variables for COD removal, leading to higher removal efficiency. According to the results of the RSM analysis, the concentration of potassium ferrate has the biggest impact on how well COD is removed. The perfect circumstances created by the modification were 92 ppm of potassium ferrate, a pH of 3, 400 rpm, and 62 minutes of contact time.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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