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 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 betablockers [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 wastewaters 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))

\[ R\% = \left( \frac{C_i - C}{C_i} \right) \times 100 \]

Where \( C_i \) 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 concentration (X1), mixing speed (X2), oxidation duration (X3), and pH value (X4) were the process variables, and COD removal 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.

\[ N = 2k (k-1) + cp \]

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

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### Nomenclature

| Symbol | Definition |
|--------|------------|
| BBD    | Box–Behnken Design |
| COD    | Chemical Oxygen Demand |
| X1     | Potassium ferrate concentration ppm |
| X2     | mixing speed rpm |
| X3     | oxidation time (min) |
| X4     | pH |
| x1     | value tagged for COD |
| x2     | speed coded value |
| x3     | time value coding |
| x4     | pH value coding |
| ao     | The intercept code |
| aij    | The impact of interaction |
| aii    | major second-class impact |
| ai     | The superior (linear) significant impact |

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### FTIR

Fourier Transform-Infra Red

### XRD

X-Ray Diffraction

### CI

Confidence interval

### DOF

Degree Of Freedom

### D

Desirability function

### Seq.SS

Sum Of Square

Adj. SS  Adjusted Sum of Square

Adj. MS  Adjusted Mean of Square

adj. R2  Adjusted Coefficient of Multiple Correlation

predR2  Predicted Multiple Correlation Coefficient

N  Number of runs

K  Number of processing parameters

Y  Represents the dependent variable (RE)

SE  Standard Error of Regression

S  Standard error of mean
characterize how the interaction terms correspond to the test data. In a second order polynomial model:

$$Y = a_0 + \sum a_i x_i + \sum a_{ij} x_i^2 + \sum a_{ik} x_i x_j$$

(3)

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 |

The method variables (independent variables) are represented by the coded form of X, where Y stands for the variable (RE), and $a_i$ and $a_{ij}$ are the pattern index numbers, $a_0$ is the intercept term, and $x_1$, $x_2$, ..., $x_k$ 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 AIII, respectively. Following the analysis of variance, the parametric statistics (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 according to the model coefficients [12, 13]. The Fisher F-test and T-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 Mintab-19 program as a pilot.

COD RE% = 79.80 + 0.1225 x_1 + 0.0604 x_4 + 0.0892 x_1 x_4 - 0.409 x_2 + 0.000894 x_1 + 0.000049 x_1^2 - 0.000667 x_2 + 0.0042 x_3 + 0.000072 x_1 x_2 - 0.000208 x_1 x_3 + 0.00917 x_1 x_4 - 0.000040 x_2 x_3 - 0.00493 x_3 x_4 + 0.00994 x_4

(4)

Table 2. Using the box-behnken experimental design

| 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         | 30         | 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  |
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.

### 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         | 9  | 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 | 97.7138 |
| 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         | 9  | 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 |

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. 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.

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

### 3.3 Impact of process factors on the effectiveness of COD removal

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.
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 | 218.39 | 15.600 | 13.68   | 0.000   |
| Linear          | 4  | 173.36 | 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   |
| X1²             | 1  | 8.037  | 10.906 | 9.37    | 0.009   |
| X2²             | 1  | 5.860  | 6.424  | 5.64    | 0.035   |
| X3²             | 1  | 2.251  | 1.920  | 1.68    | 0.219   |
| X4²             | 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  | 0.000   | 0.000   |
| Lack-of-Fit     | 10 | 12.414 | 1.241  | 1.96    | 0.384   |
| Pure Error      | 2  | 1.265  | 0.633  | 0.000   | 0.000   |
| Total           | 26 | 232.075| 0.000  | 0.000   | 0.000   |
| Model Summary   | 26 | 94.11% | 87.23% | 67.96%  |          |

![Figure 1](image1.png)

**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.
perfect circumstances created by the modification were 92 ppm of potassium ferrate, a pH of 3, 400 rpm, and 62 minutes of contact time.

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