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Modeling Leachate Treatment from Magtaa Kheira Landfill Using Coagulation-Flocculation: An Experimental Design Approach

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ABSTRACT

This study investigated the application of chemical coagulation for treating leachate generated at the Magtaa Kheira's landfill (Algeria). The effectiveness of the treatment and the influence of various factors (coagulant concentration ($Al_2(SO_4)_3$), pH, and stirring speed) on turbidity removal were optimized using response surface methodology (RSM) with a Box Behnken design. By analyzing the results, the optimal conditions predicted by the quadratic model were 1.3 g/L Al2SO4 at pH 5.3, achieving a removal efficiency of 94% turbidity

Keywords: leachate treatment, Chemical coagulants, Turbidity, Optimization, RSM

1. Introduction

Landfill leachate, a toxic mix of rainwater and landfill waste, poses a significant environmental threat. This highly polluted liquid contains persistent pollutants like organic matter and heavy metals. Effective treatment is crucial to safeguard public health and the environment [1]. Coagulation and flocculation offer a promising solution for leachate treatment because they're efficient and require minimal energy. These processes can be used alone or combined with other methods [2]. However, a key challenge lies in finding the optimal amount of coagulant needed for effective treatment. This amount can have a complex, non-linear relationship with the unique characteristics of each leachate sample. This study proposes a behavioral modeling approach using experimental design methodology as a promising solution for optimizing coagulant dosage and achieving efficient removal of turbidity from leachate

2 Experimental

Coagulation-flocculation experiments were carried out at room temperature using a standard Jar test apparatus (Lovibond type), each beaker contained 500 ml of diluted leachate. The three key variables: coagulant dosages, initial pH values and coagulation stirring speeds were tested according to the matrix obtained by the Box-Behnken design using Minitab software. Following coagulation, all samples underwent a constant, slow stirring speed of 60 rpm for 20 minutes. After a settling period of 30 minutes, a Lovibond TB 300IR turbidimeter measured the turbidity of the remaining supernatant.

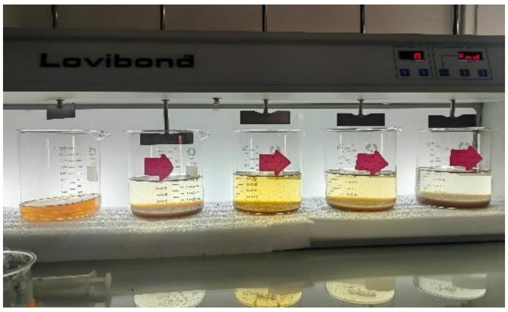

Figure1: Leachate treatment by chemical coagulation/ flocculation

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3 Results and Discussion

Analysis of the experimental results was performed and the response was evaluated in the form of second-order polynomial equations, given by:

$$\text{TUR (\%)} = 0.89000 - 0.03500\,\text{pH} - 0.00875\,\text{Dose} + 0.01625\,\text{Speed} - 0.05875\,\text{pH}^2 - 0.03625\,\text{Dose}^2 + 0.06375\,\text{Speed}^2 + 0.00000\,\text{pH*Dose} - 0.00500\,\text{pH*Speed} - 0.00750\,\text{Dose*Speed}$$

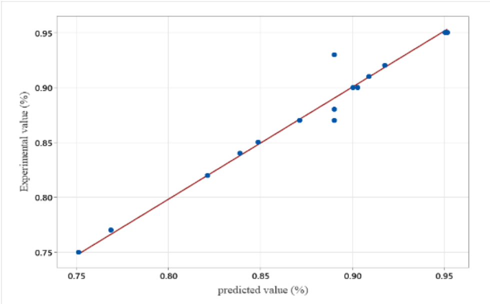


Figure2: Predicted vs. Actual Effectiveness in Reducing Leachate Turbidity

The diagnostic plot visualizing the predicted values versus the actual experimental values of the turbidity reduction efficiencies is shown in Figure 2. The data points are tightly clustered around the first bisector, indicating a very good fit between the simulated and experimental results. This is further supported by the high coefficient of determination (R^2) value for turbidity reduction: $R^2 = 95.58\%$ and R^2 (adj) = 88.96%. Therefore, the predicted mathematical model perfectly describes the experimental results.

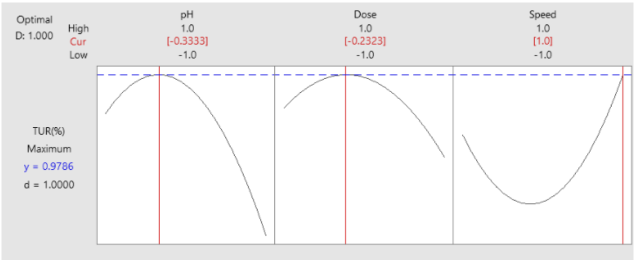
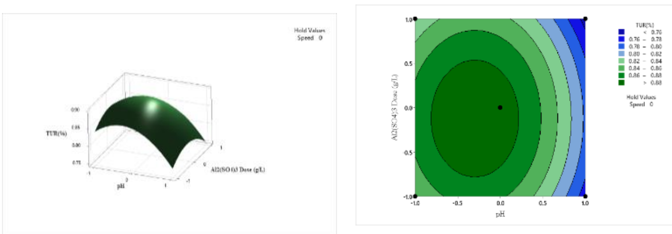


Figure3: Optimization of a single-purpose treatment process

The model's effectiveness was rigorously evaluated using ANOVA. The $F_{value(9,6)} = 14.43$, obtained using Minitab software, significantly exceeds the $F_{critical\ (9,6)} = 4.10$ listed in the Fischer-Snedecor table for two degrees of freedom (ν1, ν2) and a 5% risk, demonstrating a statistically significant relationship between model predictions and actual experimental results.



(a) (b)

Figure4: 3D surface graphics (a) and contour lines (b) for turbidity removal efficiency

The validity of the model was further evaluated through validation experiment performed under optimal conditions figured in figure 3. The average measured turbidity removal efficiency was 96%, while the model predicted an average of 97%. This close alignment between predicted and observed values confirms the model's effectiveness.

The 3D graphs in Figure 4 reveal that turbidity removal improves as we add more aluminum sulfate ($Al_2(SO_4)_3$) and increase the acidity (pH) of the solution. However, there's a limit to this improvement.

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Once the amount of $Al_2(SO_4)_3$ and pH reach a certain point, adding more won't make the water any clearer. This suggests that using too much $Al_2(SO_4)_3$ or making the solution too acidic can actually break down the flocs that remove turbidity, likely due to a phenomenon called charge reversal and dispersion [4].

5 Conclusions

The study successfully demonstrates the effectiveness of the second-order polynomial model in capturing the observed relationships. While this model's applicability may be limited to specific conditions, it holds promise for waters with similar properties to the Magtaa kheira leachate investigated here.

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