MACHINE LEARNING BASED MODEL TO ASSESS THE PERFORMANCE OF GREEN SYNTHESIZED IRON NANO PARTICLES FOR DYE REMOVAL FROM INDUSTRIAL WASTEWATER

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Introduction:

Pollution of water, especially by industrial effluents, is a dangerous menace for environmental ecosystems and human health. The release of synthetic dyes from industries like textiles, leather, cosmetics, and paper is one of the primary causes of water pollution. These dyes, due to their stable molecular nature, are not just aesthetically displeasing but also chemically persistent and toxic, posing a risk to be mutagenic and carcinogenic to human beings and aquatic organisms. Thus, their elimination from wastewater is a matter of concern in civil and environmental engineering.

Traditional dye removal methods, such as biological treatment, chemical precipitation, ion exchange, and activated carbon adsorption, tend to be inefficient, expensive, and environmentally unsustainable. The shortcomings have motivated researchers to investigate new advanced treatment technologies that are environmentally friendly and efficient. One of the breakthroughs is the application of

nanomaterials, specifically iron nanoparticles, owing to their high surface area, active sites, and outstanding adsorption capacity.

Nevertheless, the chemical synthesis of these nanoparticles can produce dangerous by-products that undermine environmental safety. In response, green synthesis methods have been proposed as a more environmentally friendly alternative. These processes harness plant-based materials to reduce metal ions, thus eliminating the use of toxic chemicals and enhancing biocompatibility.

Concurrently, the emergence of machine learning (ML) in engineering and environmental science provides an effective tool for processing complex data, detecting underlying patterns, and making precise predictions. When coupled with nanotechnology, ML algorithms can improve the comprehension of how different parameters affect dye removal efficiency, allowing the creation of solid predictive models.

This project, thus, closes the gap between sustainable nanomaterial development and smart data-driven modelling. The central aim is to prepare iron nanoparticles using green processes and use machine learning models to forecast their efficiency in decolorizing industrial wastewater. This multidisciplinary research not only promotes environmental sustainability but also facilitates the practical application of smart technologies in water treatment processes. Through intensive experimentation and data analysis, the project hopes to contribute to the creation of scalable, cost-effective, and environmentally friendly solutions for industrial wastewater management

Objectives:

Main Objective

To develop Machine Learning (ML) based model to assess the performance of green synthesized iron nano particles for dye removal from industrial wastewater

Specific Objectives

- To analyze the efficiency of Mangifera Indica in removal of dye for industrial wastewater

- To develop an optimized ML model for evaluating the effectiveness of green synthesized nano particle
- To perform a comparative study to assess the efficiency of traditional method and ML technique

Methodology:

***Materials Required*:**

- Mango leaves
- Rhodamine B dye
- Ferric Chloride (FeCl3)
- Filter paper (Whatman)
- Sodium Hydroxide (NaOH)
- Hydrochloric Acid (HCl)

Instruments Required:

- pH meter
- Hot air oven
- Spectrophotometer
- Magnetic stirrer
- Centrifuge

Sample Preparation:

1. Dried mango leaves were washed and dried again to remove any impurities.
2. The leaves were cut into small pieces and mixed with de-ionized water to create a plant extract.
3. The solution was heated and filtered to obtain a clear extract.

Experimental Procedure:

1. The plant extract and reducing agent (FeCl3) were mixed in a 1:10 proportion and stirred constantly.
2. The mixture was used to treat the Rhodamine B dye-containing wastewater.
3. The efficiency of the mango leaf extract in removing the dye was measured using a spectrophotometer.

Data Collection and Model Development:

1. Data was collected from journal papers on the removal of dyes from textile industry wastewater using plant-based extracts.

2. Parameters were finalized, and a machine learning model was developed to predict the efficiency of the mango leaf extract in removing the dye.
3. The model was validated and tested using the collected data.

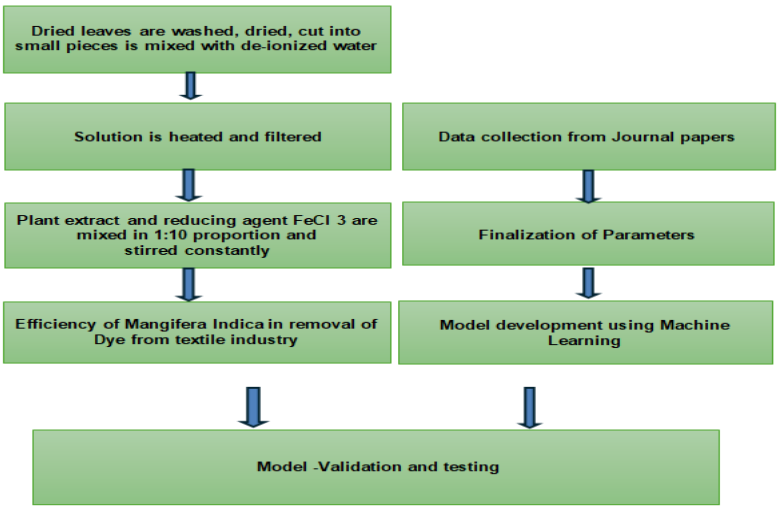

Fig. 1: Methodology

Result:

The experiment was conducted to obtain the optimum pH, initial dye concentration, initial extract by assessing maximum dye removal. Fig.2 indicates the maximum removal of dye for pH 9 of extract. The removal efficiency of dye was analysed by varying pH 3, 4, 8 and 9. Similarly removal efficiency of dye was analysed by keeping pH 9 as constant and by varying the initial concentration of Rodamine B dye. Finally the optimum extract concentration was identified. The optimum values identified are extract concentration 1.5mL and Rhodamine B dye 4 x 10^{-4} mg/L.

The Machine Learning algorithm was identified and training the model using ML dataset obtained from literature survey. The data set includes pH, dosage, dye concentration and Dye removal efficiency. Then validation of the model by comparing predicted and actual performance.

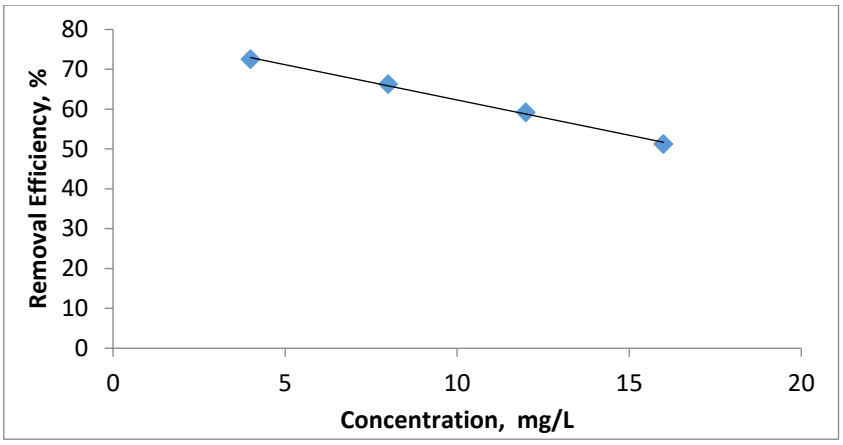

Fig 2: Removal efficiency of dye for pH 9

Conclusion

- Optimum condition obtained for maximum dye removal from simulated sample is pH 9, extract concentration 1.5mL and Rhodamine B dye 4 x 10^{-4} mg/L
- Machine Learning algorithm developed considering five parameters using 50 set of data obtained from literature survey
- Comparative study between traditional method and ML technique regarding removal efficiency of dye showed difference of 15%

Project Outcome & Industry Relevance

Smart Wastewater Treatment Plants

- This helps industries minimize trial-and-error and automate decision-making, improving both efficiency and sustainability.

Green Chemistry in Industrial Applications

- Industries can adopt eco-friendly nanoparticle synthesis methods using plant extracts, reducing dependency on toxic chemicals and aligning with green manufacturing policies and environmental regulations.

Quality Control and Monitoring

- The ML model can be used for continuous monitoring of effluent treatment performance, allowing industries to detect performance drops early and adjust parameters proactively.

Project Outcomes and Learning's

Development of a Predictive ML Model

- A machine learning model (e.g., Linear Regression, Random Forest, or Neural Network) was successfully developed to predict the dye removal efficiency of green-synthesized iron nanoparticles based on key parameters like pH, nanoparticle dosage, contact time, and dye concentration.

Data Collection and Preprocessing

- Experimental and/or literature-based datasets were collected and cleaned. Relevant features were selected for model training, ensuring high accuracy and generalization capability.

Green Synthesis Validation

- Iron nanoparticles were synthesized using environmentally friendly methods (e.g., plant extracts), and their properties were characterized using techniques like UV-Vis, SEM, or FTIR.

Performance Assessment

- The model could successfully assess and predict the performance of nanoparticles across different scenarios, helping in understanding the optimal conditions for maximum dye removal.

Future Scope:

The future scope of this project includes:

1. Performance Prediction & Modeling:
    - With more data, ML models (e.g., regression, random forests, neural networks) can be refined to more accurately predict dye removal efficiency.
    - Models can adapt to different dye types and wastewater compositions.
2. Integration with IoT Systems:
    - Smart wastewater treatment systems could integrate these models to provide real-time monitoring and automated decision-making.
3. Comparative Analysis:
    - ML can be used to compare the performance of different types of green-synthesized nanoparticles (e.g., ZnO, TiO_2) for various contaminants, not just dyes.