Peer-Reviewed Structured Abstract

Modeling and Predicting Petroleum Wastewater Treatment Outcomes with Neural Networks

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Summary

This study investigates AI techniques for improving petroleum wastewater treatment. Using MATLAB, it develops two machine learning models, multilayer perceptron neural networks (ANNs) and support vector machines (SVMs), to predict pollutant levels and optimize treatment processes. Data from 26 weekly samples, including chemical oxygen demand (COD), ammonia (NH3), and nitrate (NO3), are utilized. The dataset is split into training and testing sets, with values normalized for consistency. ANN models are trained with various algorithms, while SVM models use Quadratic Programming and Gaussian kernel functions. Results indicate that SVMs surpass ANNs in prediction accuracy, particularly with limited data. A user-friendly graphical interface is created to facilitate quick and accurate predictions, enhancing the practical application of these models in real-world scenarios. This software aids efficient management of treatment processes in the petroleum industry, showcasing the potential of AI-driven solutions for sustainable wastewater treatment.

Background

The global water crisis highlights the urgent need for effective wastewater treatment, particularly for industrial effluents that are highly toxic and challenging to manage. Petroleum wastewater, a byproduct of refineries, contains hazardous hydrocarbons posing significant environmental risks. Traditional methods are insufficient for these complex issues, but AI has introduced new opportunities to enhance treatment processes. Recent AI advancements have significantly improved these processes.

Due to laboratory studies' high costs and time-intensive nature, modeling and optimization software has become highly desirable in various engineering and scientific fields. AI offers high-speed, accurate modeling capabilities, reducing the need for extensive lab testing and lowering operational costs. Techniques like artificial neural networks (ANNs) and support vector machines (SVMs) are extensively studied for their predictive and optimization capabilities. ANNs excel in managing complex, nonlinear relationships among wastewater parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), and total suspended solids (TSS), enhancing process efficiency and reducing costs [1]. SVMs are known for their robustness in classification and regression tasks, demonstrating high accuracy in predicting pollutant levels and optimizing treatment protocols [2].

Despite these advancements, gaps remain in the comprehensive application of these models, particularly in integrating real-time monitoring and fault detection systems [1]. This research addresses these gaps by using ANNs to model and predict the quality of petroleum wastewater post-treatment and comparing the performance of SVMs to identify the most accurate and

efficient approach. This dual-method comparison provides unique insights into the strengths of each AI technique, paving the way for more effective and sustainable wastewater treatment solutions [2].

Methodology

This study uses MATLAB to implement two machine-learning techniques to predict pollutant levels in petroleum wastewater treatment outflow and optimize related processes (presented in Fig. 1. The primary model is a multilayer perceptron neural network (ANN), while the secondary model uses support vector machines (SVMs) for comparison.

In the first set of modeling with MLP, 26 weekly samples are collected from the inlet and outlet of a gas refinery's wastewater treatment unit. Parameters measured in the input flow include chemical oxygen demand (COD), ammonia (NH3), and PH, COD, NH3, and nitrate (NO3) are measured in the output stream. The dataset is divided into training (75%, 20 samples) and testing (25%, six samples) sets. All values are normalized to a scale of +1 to -1.

Three separate ANN models are developed, each targeting a specific output parameter (COD, NH3, or NO3). The optimal network structures are determined through trial and error. The first model, predicting COD, uses a two-layer network with five neurons per layer, employing a radial basis function in the first layer and a sigmoidal function in the second, trained using the Levenberg-Marquardt algorithm. The second model, predicting NH3, uses two hidden layers with five neurons each and radial basis functions trained with the gradient descent algorithm. The final model, predicting NO3, consists of a single hidden layer with ten neurons, using radial basis functions and trained with a combination of gradient descent and momentum backpropagation algorithms.

The performance of these models is evaluated based on their prediction accuracy, demonstrating the efficacy of ANNs in optimizing petroleum wastewater treatment processes.

SVM is employed to enhance the accuracy of predicting pollutant concentrations (COD, NH3, NO3) in the effluent of petroleum industry treatment units. Three SVM models are developed using MATLAB, each targeting a specific pollutant. Optimal hyperplane separation is achieved through Quadratic Programming (QP) techniques. To handle complex, non-linear data, a Gaussian kernel function is used to map the data into a higher-dimensional space. Key SVM parameters (γ, K, ε) are manually tuned to optimize performance. The models demonstrate high accuracy in both the training and testing phases, with minimal error and a regression coefficient of one.

Results and Observations

The comparative analysis of support vector machine (SVM) and multilayer perceptron (MLP) models for predicting petroleum wastewater treatment outcomes shows a significant decline in R-squared values for the MLP model during validation, likely due to limited data. Despite this, SVM models perform robustly, accurately simulating the system's behaviour and closely matching experimental data. This suggests that SVMs are more reliable for this application under the given data constraints, providing more accurate and consistent predictions of treatment outcomes.

A user-friendly graphical interface was developed to enhance the practical application of these models further. This interface allows users to input COD values, select the desired output parameter and model, and obtain the predicted output by pressing a calculation button. Additionally, it displays diagrams related to each model's training and testing stages, offering

a comprehensive overview of the model's performance. This software can be used in real-world scenarios to facilitate quick and accurate predictions of wastewater treatment outcomes, enabling more efficient and effective management of treatment processes in the petroleum industry.

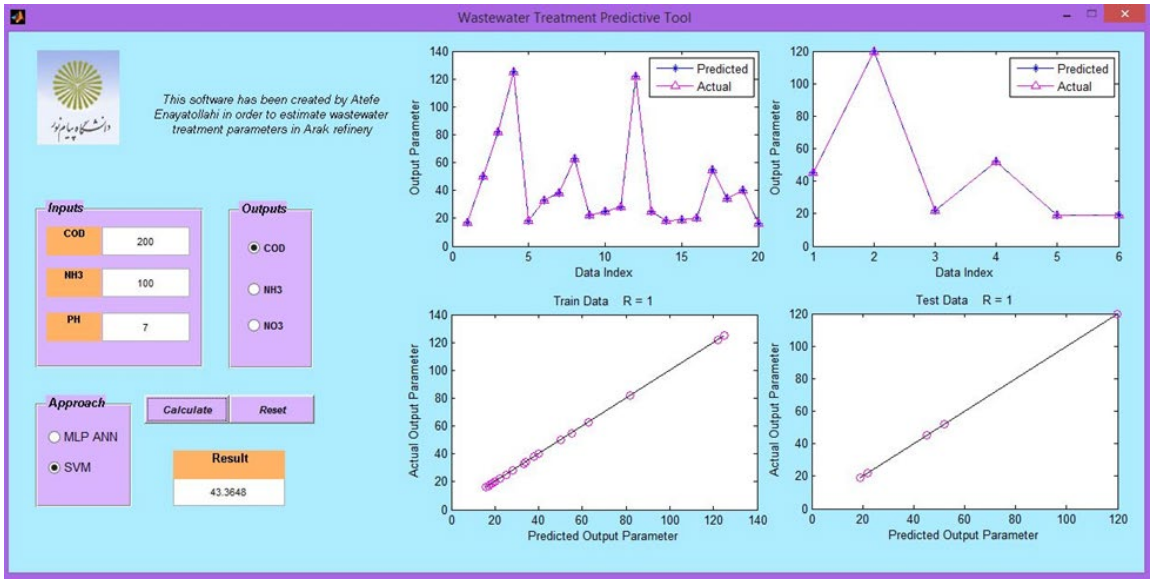

Fig. 1. The comparative analysis of support vector machine (SVM) and multilayer perceptron (MLP) models for predicting petroleum wastewater treatment outcomes.

Conclusions

The comparative analysis underscores the superior performance of SVMs over MLPs, particularly with limited data. SVM models accurately simulate the system's behaviour and closely match experimental data. The developed graphical interface also enhances practical application, enabling quick and accurate predictions of wastewater treatment outcomes. This software supports efficient management of treatment processes in the petroleum industry, highlighting the potential of AI-driven solutions for sustainable wastewater treatment.

References

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2. Wang, Y., Cheng, Y., Liu, H., Guo, Q., Dai, C., Zhao, M., & Liu, D. (2023). A Review on Applications of Artificial Intelligence in Wastewater Treatment. Sustainability, 15(18), 13557.