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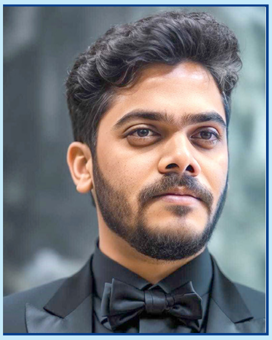
AI-ML DRIVEN CONTROL OF EFFLUENT TREATMENT PLANTS FOR SUSTAINABLE PULP AND PAPER MILL OPERATIONS



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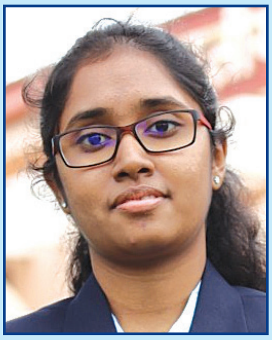

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Abstract:

This technical paper delves into the transformative integration of Artificial Intelligence (AI) and Machine Learning (ML) in Effluent Treatment Plants (ETPs) within the pulp and paper industry. The imperative for efficient wastewater management in water-intensive mill processes has propelled the adoption of internal ETPs, yet challenges persist. The paper explores the limitations of conventional control of ETPs and subsequently introduces AI and ML as game-changers, offering real-time optimization, predictive maintenance, and advanced control of ETPs. A specific study, utilizing a hybrid physicochemical treatment, demonstrates the tangible benefits of AI/ML in reducing chemical consumption, increasing energy savings, and enhancing treated water quality. The methodology employed in the study, from goal definition to results, serves as a valuable guide for the implementation of AI/ML technologies in optimizing effluent treatment processes in the pulp and paper industry.

Keyword: *Artificial intelligence (AI), Effluent Treatment Plant (ETP), Chemical Consumption, Water Treatment, Total Suspended Solids (TSS)*

Introduction

As mills utilize water-intensive processes involving various chemicals and organic materials, leading to the generation of wastewater rich in organic compounds, suspended solids, and potentially harmful substances, effective treatment is indispensable to mitigate environmental risks and safeguard ecosystems [1].

Effluent Treatment Plants (ETPs) play a pivotal role in the sustainable operation of pulp and paper mills by managing and treating wastewater generated during the production process. The control of these ETPs is critical to ensure compliance with environmental regulations, minimize the ecological impact, and sustain the efficiency of mill operations [2]. Environmental performance indicators (EPI) and operational indicators are used to stipulate significant aspects attributed to industrial environmental compliance. The EPIs can be further divided into two categories i.e., management and operational performance indicators.

Management performance indicators are related to the management efforts to influence the environmental performance of the organizational operations, whereas operational performance indicators are related to the process and other operational activities of the organization. These address the issue of raw material consumption, energy consumption, water consumption in the organization, the quantities of wastewater generated, other solid wastes & emissions generated from the organization, and so forth [3].

Limitations of In-House Effluent Treatment to a Paper Mill:

As compliance regulations regarding effluent management become increasingly prevalent, the installation of internal ETPs becomes more logical for mill owners. However, this transition brings forth several challenges that impact operational, financial, and capital resources.

These challenges are outlined as follows:

1. Effluent Variability: Effluent characteristics can vary, causing fluctuations in treatment efficacy. Dealing with variations in influent quality demands adaptable treatment processes and operational adjustments. Meeting stringent environmental standards demands precise and consistent operations, posing challenges in maintaining compliance consistently.

2. Monitoring and Control: Effective monitoring and control of treatment parameters are essential for efficient operations. Maintaining precise control over factors like pH and flow rates can be operationally demanding.

3. Chemical Usage and Disposal: Treatment processes involve the use of chemicals for effective purification. Proper handling, storage, and disposal of these chemicals pose operational challenges, necessitating compliance with safety standards.

4. Energy Consumption: Treatment processes within ETPs consume significant amounts of energy. Managing energy consumption to minimize costs and reduce the environmental impact can be operationally challenging.

5. Capital Allocation: Allocating significant capital to ETP installation and operation might restrict the availability of funds for other essential operational or developmental aspects of the pulp and paper mill. ETPs often demand considerable space within the mill, potentially conflicting with other operational areas.

Incorporation of Artificial Intelligence in Effluent Discharge Regulation:

In the quest for enhanced efficiency and sustainability in the pulp and paper industry, Artificial Intelligence (AI) and Machine Learning (ML) have emerged as transformative tools. Integrating AI/ML methodologies into water treatment programs offers a comprehensive approach to addressing challenges inherent in effluent management. These advanced computational technologies leverage extensive datasets to predict and adapt treatment processes, effectively managing the variability present in effluents.

AI-driven real-time monitoring and control systems enable rapid insights, facilitating precise adjustments in critical treatment parameters. Moreover, AI algorithms optimize chemical dosing by accurately predicting the requisite dosage for efficient treatment, thereby curtailing operational expenditures and minimizing chemical waste disposal [4]. Whereas, ML models discern inefficiencies, offering tailored energy-saving strategies that reduce overall energy consumption while preserving treatment efficacy.

Furthermore, predictive maintenance, powered by AI/ML, ensures equipment reliability, optimizing capital allocation by mitigating downtime and extending equipment lifespan. The integration of AI/ML technologies systematically optimizes resource utilization, ensures steadfast regulatory compliance, and enhances operational efficiency within water treatment programs, establishing a robust framework for addressing the diverse challenges encountered in effluent management.

Our Study:

The incorporation of AI/ML-driven devices specifically targeting the mechanical, operational, and chemical facets of ETP operation, can elevate & maintain treated water quality while ensuring optimal resource utilization, thereby driving water & energy savings across various operations while championing the industry's environmental goals.

The goal was to ensure adherence to specifications and performance requirements to maintain water quality consistency, which was achieved by implementing an AI/ML-augmented Effluent Treatment Program specifically targeting real-time optimization in ETPs.

The study investigated the effectiveness of a physicochemical treatment process for treating wastewater from a pulp and paper mill. The treatment [5] involved several stages:

1. Primary Settling: This initial stage involved plain settling for a hydraulic retention time (HRT) of four hours, which effectively reduced 30% of the pollution load in effluent water.

2. Coagulation-Flocculation-Aided Clarification: Different coagulants were tested, including inorganic coagulants and a combination of inorganic, organic coagulants, and conventional flocculants.

3. Activated Carbon Adsorption: After chemical treatment, the water was further treated with activated carbon in a batch reactor for up to four hours. This step was crucial to meet the paper mill water quality standards, achieving high pollutant reductions in the range of 95-99% for turbidity, COD, TOC, TSS, and color.

The study concluded that this hybrid physicochemical treatment, combining sedimentation, coagulation-flocculation, and activated carbon adsorption, was effective in significantly reducing the pollutant load in the effluent from paper mills and meeting the required discharge standards.

Methodology:

The study was conducted at one of the leading Indian pulp & paper mills over a period of 30 days. The client experienced high variability in the characteristics of treated water, affecting operational costs.

The following steps [6] were followed in designing a prediction model for effluent treatment:

Goal Definition:

The primary objective of employing an AI/ML approach in the Effluent Treatment Plant (ETP) of a pulp and paper mill is to develop predictive models and control strategies for optimizing effluent treatment parameters. This entails harnessing AI/ML algorithms to predict and regulate critical indicators in real-time. Additionally, it also aims to gauge the high-performing proportions in the usage of inorganic and organic coagulants by generating adaptive models that enhance treatment efficiency, minimize suspended solids, and organic matter, and improve overall effluent quality within the ETP.

Data Collection:

During the effluent treatment process, real-time data for pivotal parameters including pH, Total Suspended Solids (TSS), Turbidity, Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), and Color were systematically acquired using specialized sensors. This dataset formed the fundamental basis for subsequent analysis and modeling stages.

Data Cleaning:

Pre-processing techniques are applied to prepare data for analysis and modeling. These techniques play a crucial role in extracting actionable insights from raw datasets. The pre-processing steps encompass handling missing data, outlier removal, and standardizing or scaling variables to establish a uniform range, ensuring the data is appropriately conditioned for further analytical procedures.

Data Analysis:

The gathered dataset underwent multivariate analysis to discern key parameters in the ETP process. This analysis focused on aspects such as chemical composition, operational elements in the treatment process, and specific stages within the ETP operation. By scrutinizing the interrelationships among diverse parameters, the most influential factors affecting treatment efficacy were identified. These critical factors were then employed in the development of predictive models for optimizing ETP performance.

Modeling:

Based on the identified relationships, a predictive model was formulated, serving as the foundation for the development of a dosage model. These models integrated target values and observed data trends, aiming to optimize chemical consumption in the ETP process. Evaluation of prediction model accuracy was conducted through a comparative analysis between actual and target values.

This study was performed live to demonstrate the model's precision to the customer. Subsequent fine-tuning of the model was performed based on its real-time performance to enhance overall efficiency.

Results:

Enabled with AI/ML models, the treatment program demonstrated optimization in chemical consumption, energy savings, and overall operational efficacy. This implementation also yielded heightened consistency in the characteristics of treated water, explained in detail as follows:

1. Real-time Optimization of Chemical Consumption - The AI/ML-based system, resulted in a 28% reduction in terms of total cost/kg chemical consumption during the treatment process, showcasing the system's ability to enhance efficiency in chemical utilization. The system tested different coagulant iterations, including inorganic coagulants and a combination of inorganic + organic coagulants + conventional flocculants. The results showed:

a. Alum (1200 mg/L) at pH 6.5 proved to be the most effective coagulant, achieving 80% turbidity removal, 55% COD reduction, 36% TOC reduction, 78% TSS removal, and 76% color removal.

b. The ML program modified the coagulation-flocculation process. The alum dosage was reduced from 1200 ppm to 100 ppm, supplemented with an average of 15-25 ppm of a specialty HABER coagulant, and 0.5 to 2 ppm of flocculants. This innovative approach enhanced the efficiency of the physicochemical treatment for significant pollutant reduction in paper mill effluent, aligning with required discharge standards, achieving 89% turbidity removal, 75% COD reduction, 58% TOC reduction, 86% TSS removal, and 89% color removal **(Fig. 1-5).**

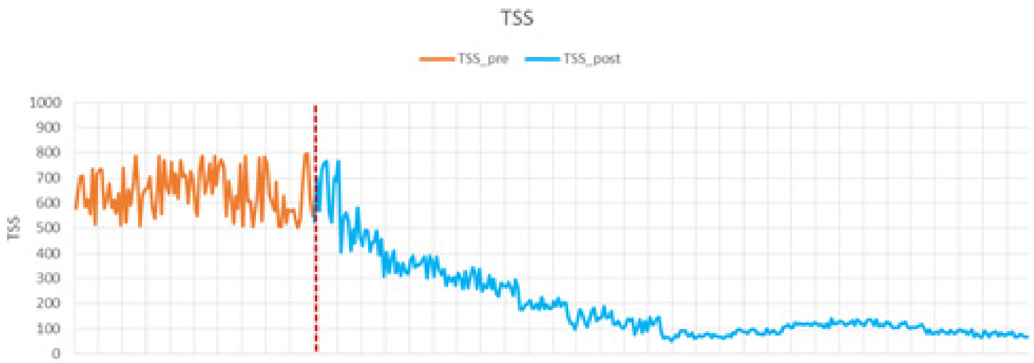

Fig. 1: Pre & Post-AI Values of TS

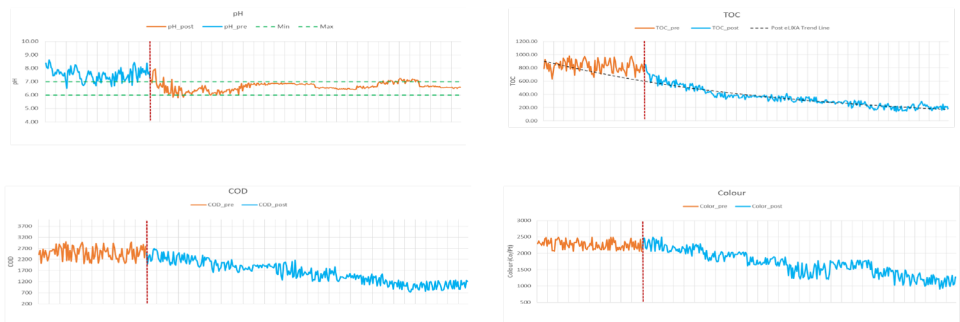

Fig. 2-5: Pre & Post-AI Values of pH [2], TOC [3], COD [4], Colour [5]

2. Energy Savings through Operating Conditions Optimization - Simultaneously, the AI/ML-based system, in conjunction with the control model, dynamically optimized operating conditions in real time. This proactive strategy delivered a 25% increase in energy savings, reducing the consumption from ~28 to 21 kWh/day, affirming the system's effectiveness in resource utilization and sustainability **(Fig. 6).**

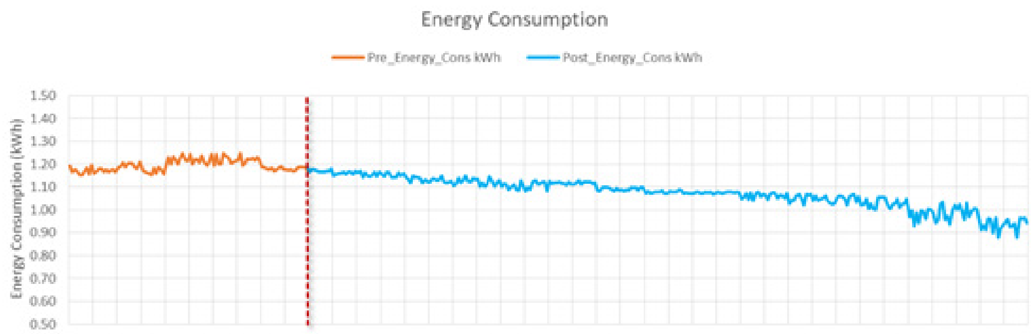

Fig. 6: Energy Consumption Reduction

3.Enhanced Consistency and Quality Assurance - The implemented model consistently delivered precise outcomes, ensuring a heightened level of water quality in the treated effluent. This not only upheld superior water quality standards but also realized significant reductions in operational costs, affirming the model's contribution to efficiency and cost-effectiveness.

4.Live Data Analysis - Operating on live data streams, the model exhibited superior capabilities in capturing and responding to instances of fluctuations. This real-time adaptability was pivotal in addressing dynamic variations within the treatment process.

5.Iterative Development for Continuous Improvement - The AI/ML program underwent continuous development and refinement, ensuring the predictive model consistently upheld treated water quality within targeted values. This iterative approach affirmed the program's commitment to continuous improvement, maintaining effectiveness and reliability in optimizing effluent treatment plant operations.

Conclusion:

The paper emphasizes the pivotal role of AI/ML in revolutionizing effluent treatment for pulp and paper mills. Acknowledging the challenges of internal ETPs, the study showcases the effectiveness of an AI/ML-driven physicochemical treatment process. The integration yields substantial reductions in chemical consumption, an increase in energy savings, and consistency in treated water characteristics. The iterative development approach ensures continuous improvement, making AI/ML an indispensable tool for optimizing ETP operations. This research delved into sustainable and technologically advanced effluent management systems, aligning with industry environmental goals and ensuring operational efficiency.

Abbreviations:

AI: Artificial Intelligence

ML: Machine Learning

KPI: Key Performance Indicator

ETP: Effluent Treatment Plant

EPI: Environmental Performance Indicator

TSS: Total Suspended Solids

COD: Chemical Oxygen Demand

TOC: Total Organic Carbon

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