Machine Learning Methods for Coagulant Dose Estimation at the Lethbridge Water Treatment Plant

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Abstract. Machine learning methods have the potential to 'learn' complex chemical processes from large, properly prepared data sets. These models can be used to leverage historical data to drive better process decisions. Custom machine learning models of the coagulation process were developed for the City of Lethbridge Water Treatment Plant using various data selections, processing techniques, and model architectures. These models underwent a desktop assessment using process data and yielded promising results, including a 24% reduction in coagulant chemicals needed to meet treatment objectives. The models were subsequently tested full scale at the Water Treatment Plant in May – June 2022. During the testing period the models provided coagulant and polymer dose recommendations for both stable and rapidly changing raw water conditions. During stable conditions the model helped operational staff to reduce the coagulant chemical used while exceeding treatment objectives. In rapidly changing, poor raw water conditions the model provided immediate adjustment recommendations that helped maintain excellent filterability and treated water quality. A project is now underway to fully implement the models at the Water Treatment Plant, giving the operators real time recommendations for coagulant and polymer doses. Potential benefits of the full implementation include improved use of coagulation chemicals to achieve treatment objectives, reduced chemical costs, reduced residuals, and greater operational support to operators.

Artificial Intelligence; Machine Learning; Coagulation; Water Treatment

Introduction

Coagulation Background

Coagulation chemistry is a complex process impacted by several variables and is regarded as "the single most important factor affecting treatment plant performance"[1]. Traditional water treatment plant operation relies on operator judgement based on raw water conditions, treatment conditions, manual jar testing, and past experience to determine suitable chemical doses to achieve adequate coagulation. The complexity and importance of the process often results in operators mildly overdosing coagulant to ensure adequate treatment performance. Overdosing coagulant may have negative treatment, environmental, and budgetary impacts. When coagulant chemicals are not dosed properly the entire treatment process can degrade, adding significant stress to water treatment plant staff and management.

Linear numerical models and control philosophies are not effective for control of coagulant and polymer doses under varying water conditions. While some online water quality technologies do offer an indication as to whether additional coagulant is needed, these technologies do not provide the user with expected treatment results or the optimality of the coagulant/polymer blend, and such technologies can be an operational challenge to maintain.

Machine Learning Background

Machine learning is a subset of artificial intelligence that "gives computers the ability to learn without being explicitly programmed"[2]. Large data sets are used to train models of varying architectures, allowing the models to 'learn' complex non-linear relationships from past data. These models can then be used to predict the results to challenging multiple input problems.

Problem Statement

Can machine learning methods be used to model the coagulation and water treatment process such that chemical doses can be optimized using the model?

Methodology

Data selection, pre-processing, and correct machine learning model architecture are critical to the accuracy of machine learning models. Varying data selections, pre-processing methods, and model architectures were employed using approximately 100,000 data points to prepare machine learning models of the coagulation process. Models were trained to estimate both turbidity removal and natural organic matter removal efficiency under various process conditions and chemical dosages. These models were evaluated against a test data set that was withheld from their respective training sets to determine the respective model accuracy.

After models with sufficient accuracy were prepared a desktop simulation run was completed. A month of production data not incorporated in the training and testing was modelled with suggested coagulant dosages applied. The desktop simulation suggested a 24% reduction in coagulant was achievable while maintaining clarifier effluent and treated water quality.

In May and June of 2022 a full scale trial of the coagulant dose estimation system was undertaken. This included implementing the model recommendations for coagulant and polymer doses to one of the Lethbridge Water Treatment Plant's two clarifiers. Filterability, unit filter run volumes, and treated water quality were rigorously monitored as part of the trial.

Results and Discussion

The trial results can be classified in to two main operational periods. For the first 20 days of the trial, raw water turbidity generally ranged from 15 - 45 NTU and raw water UV transmittance ranged 81% – 92%. During this period the raw water and operating conditions were relatively stable. Over the same period filterability, unit filter run volumes, and treated water quality targets were met without exception using noticeably less coagulant and emulsion polymer than would have typically been used.

In the last week of full scale testing, a regional wet weather event occurred, causing river turbidity to reach as high as 1300 NTU and a sustained turbidity >500 NTU for more than 35 hours. Raw water UV transmittance ranged from 75% - 82%. Clarifier effluent turbidity was maintained below 0.4 NTU for the first 8 hours of the event, after which the solid contact clarifier blankets were lost due to insufficient clarifier blowdown. Without the blankets clarifier turbidity rose to nearly 5 NTU, however even under these conditions all other indicator of good coagulation, including filterability, filter ripening times, and unit filter run volumes, maintained their performance. Throughout the event post filtration UV transmittance was maintained over 94% and turbidity less than 0.1 NTU.

Two weeks after full scale testing was completed the Oldman dam upstream of the WTP released a significant volume of water, resulting in river turbidity reaching as high as 1500 NTU and a sustained turbidity >500 NTU for more than 30 hours. Raw water UV transmittance ranged from 78% - 89%. To help manage the rapidly changing river conditions the model was used to provide recommendations to the operator for one of the clarifiers. Coagulant and polymer doses were modelled and adjusted for the duration of the event, resulting in an average clarifier effluent turbidity of less than 1.0 NTU and an average post filtration UV transmittance of over 95% during the 30 hour period. There were no issues with filter runs or bringing filters online for the duration of the event, and post filtration turbidity remained less than 0.1 NTU.

During this same event the water treatment plant's other clarifier was operated using operator input coagulant and polymer dosages that were up to 50% higher than those recommended by the model. After observing negative results in filterability from this clarifier's effluent the dosages were adjusted to follow the model's recommendations.

The full scale trial was deemed successful, and a project is currently underway to implement the system at the City of Lethbridge water treatment plant. The models will serve to provide data driven recommendations to operators in all scenarios, allowing for knowledge retention and improved operations. The implementation will include a fully air gapped model with no requirement for internet access. As the model is updated on a regular basis with additional historical data the accuracy of the model is expected to improve.

Conclusions

Machine learning methods have been successfully trialled at the Lethbridge Water Treatment Plant for coagulant and polymer dose control, and full implementation is underway. When fully implemented the models will provide recommendations for coagulation chemical dose set points. Potential benefits of the full implementation include improved use of coagulation chemicals to achieve treatment objectives, reduced chemical costs, reduced residuals, and greater operational support to operators.

References

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[2] Samuel, A.L. (1959), Some studies in machine learning using the game of checkers. IBM Journal of Research and Development (Volume:3, Issue:3), 210.