Real-time Integrated CT Control for PAA Disinfection in Municipal Wastewater Treatment

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**keywords, key takeaway**

# Introduction

The goal of this work is to reduce the cost of disinfection using peracetic acid (PAA) at the Robert W. Hite Treatment Facility operated by the Metro Wastewater Reclamation District (MWRD) in Denver, CO. Due to differences between the initial PAA pilot and full-scale disinfection installation (e.g., geometry and residence time of disinfection basin, variable influent E. coli concentrations, variable PAA initial demand), MWRD experienced an instance of exceeding its E. coli discharge limit for a single day while operating at the dose initially recommended by the pilot study (1.2 mg/L). To ensure another exceedance does not occur, MWRD has continually increased PAA dose to respond to poor E. coli inactivation. This approach has increased PAA chemical costs substantially and has resulted in a re-evaluation of the PAA dosing strategy.

Manoli et al. (2019) proposed a novel CT-based PAA dosing strategy derived from first principals. A double-exponential model of microbial inactivation was solved given a first order model of PAA decay and an n-CSTR hydraulic model. The formulation predicted effluent fecal coliform concentrations given influent fecal coliform concentration and the integrated CT (ICT). ICT was solved given the initial concentration of PAA (denoted *Cd* here), the PAA decay constant (*k*), and the initial demand of PAA (*D*). The PAA decay constant was estimated by solving for various ICTs using Excel Solver and in for Manoli et al. ranged from 0.01-0.02 min-1. Given the average ICT for a given hour, fecal coliform samples were taken at the inlet and outlet to fit the microbial inactivation model. The fitted parameters (β, kd, m, kp) varied with each batch, which demonstrates that the first order model may not fully describe PAA demand and decay kinetics in a real water matrix, requiring four degrees of freedom to fit the model to the observed data.

Alternatives to predicting PAA concentration using first order models are non-deterministic approaches, such as statistical learning and machine learning. Both approaches have the advantage of being able to consider the impact of multiple variables without a known relationship. However, water quality and operational parameters of a wastewater treatment system are too complex for many statistical models (e.g., generalized linear models). Therefore, neural networks (NN) were used to predict concentrations of PAA throughout the disinfection basin and instantaneous CT. The purpose of integrating a neural network model with the CT-dosing strategy is to accurately predict CT by adapting to real-time changes in *k* and *D* by incorporating process information.

# Materials and methods

A total of 143 observations were collected for this study. From October 2, 2018 through Oct 15, 2018, three daily grab samples were taken (1) immediately downstream of the PAA dosing location and (2) halfway through the disinfection basin. Online data recorded at the time of collection were also included; specifically from nutrient and total suspended solids (TSS) sensor measurements at the end of the secondary treatment process and ultraviolet-visual spectrum measurements (YSI CarboVis®, Yellow Springs, OH, USA) at influent of the disinfection basin.

| Process Variables | Location | Sampling |
| --- | --- | --- |
| Pump Flow Based PAA Dose | Disinfection | Online |
| PAA 1 min Sample | Disinfection | Grab |
| PAA 1 2 Basin Sampling | Disinfection | Grab |
| N Eff TSS Conc | Disinfection | Online |
| Temp of NSEC Main Ch | Secondary | Online |
| Temp of the Atmos | Secondary | Online |
| Secondary Effluent Flow | Secondary | Online |
| N Basin Outfall | Disinfection | Online |
| CODto mg L | Disinfection | Online |
| TSS mg L | Disinfection | Online |
| UVT | Disinfection | Online |
| CODds mg L | Disinfection | Online |
| SACto 1 m | Disinfection | Online |
| NSEC Aerobic SRT | Secondary | Online |
| NSEC Effluent NH3 | Secondary | Online |
| NSEC Effluent NO3 | Secondary | Online |
| NSEC Effluent OP | Secondary | Online |
| NSEC Effluent TSS | Secondary | Online |
| NSEC Effluent NO5 | Secondary | Online |
| NSEC Effluent Flow | Secondary | Online |

To predict and simulate real-time disinfection, neural networks were trained on 80% of the avalible data (114 observations) and tested on the remaining 20% (29 observations) using a rolling window approach. To illustrate: (1) the neural network model is trained to predict the PAA concentration at one of the two sampling locations using observations 1-114, (2) the trained model is used to predict the next observation in time (115); (3) the rolling window moves forward one timestemp and steps 1 and 2 are repeated using observations 2-115 for training and 116 for testing. The rolling window continues to move forward and the model retrained-tested until all 29 observations have been tested. To evaluate the performance of the neural network approach, the training model fit is calculated using R2 and the actual PAA concentration is compared to the model prediction using root mean squared error (RMSE).

Various neural network configurations are tested in order to determine (1) the optimal model inputs and nodes and (2) which water quality variables impact PAA disinfection potential. For each test, models containing 3-9 process inputs are constructed using 2 hidden layers. The first hidden layer contains half of the number of process inputs and the second hidden layer contains half the number of the first (both rounded up in the case of a fraction). For each configuration, model R2 and RMSE are averaged across the 29 predictions and ranked. The best performing models are analyzed for how frequently each process variable is included to identify correlations between PAA concentration in the disinfection basin, water quality, and upstream treatment performance.

From the PAA concentration predictions at two points in the disinfection basin, total disinfection potential can be calculated by *CT*. CT is the sum of the area of the curve of PAA concentration as a function of time. Assuming a single exponential model describes the consumption of PAA throughout the disinfection basin, CT is calculated from:

where is the concentration of PAA as a function of hydraulic retention time, is the total hydraulic retention time in the disinfection basin, is the 1st order exponential decay constant, and is the solution to the 1st order exponential decay at . is equivalent to the initial PAA dose minus instantaneous PAA demand (). The curve is fit to the two PAA samples collected at each of the 143 sampling events and compared to the curve fit by the neural network predcition to determine if neural networks could be used in lieu of an online PAA analyzer for CT-based dose control.

# Results

NN Models were built to predict PAA at the “1-min” and “1/2 basin” sample point to predict C1 and C2