NWRI GRADUATE FELLOW FINAL REPORT

DATE:	June 30th, 2023
Project Title:	Direct Online Monitoring of Direct Potable Reuse System
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Background and Introduction

Overview

The central focus of this research project lies in exploring the effectiveness of a novel direct online monitoring system in a 2 gallon per minute (GPM) direct potable reuse (DPR), ensuring safety and reliability while simultaneously reducing environmental impact by maximizing water recovery. While current monitoring practices are effective, there is a growing need for advancements that provide more real-time and comprehensive data.

Hypothesis

We hypothesize that this direct online water quality monitoring system will successfully demonstrate its ability to maintain safety and reliability in the pilot advanced water purification (AWP) system for DPR.

Study Goals

The study aims to test the viability of novel water quality monitoring technologies developed by our Japanese collaborators by implementing them in the 2-GPM pilot-scale AWP system that was designed, constructed, and operated by our research group at Texas State University. The pilot AWP system will be challenged with different configurations of treatment trains, as well as intentionally adding disinfection byproduct (DBP) precursors to test the efficacy of the system.

Objectives of Research Project

The objective of this research project is to demonstrate the practicality of an online monitoring system in the pilot scale AWP system for DPR research by implementing novel water quality analyzers for bacterial counts, bromate (BrO_3^-), and *N*-nitrosodimethylamine (NDMA). The 2 GPM pilot-scale AWP system consists of multiple unit processes, including ozonation (O_3), for oxidizing and inactivating bacteria and viruses as well as removing organics, biological activated carbon (BAC) for the removal of organics through biodegradation, ultrafiltration (UF), to remove suspended solids, bacteria, and viruses, reverse osmosis to remove ions and toxic chemicals, and ultraviolet (UV) with hydrogen peroxide and an advanced oxidation process (AOP), disinfects pathogens and degrade trace organics. With a successful implementation, these analytical instruments will continuously monitor the formation, presence, and removal of DBPs and bacteria and show that this AWP train can produce safe and clean drinking water.

Need(s) Served by This Research

Current DPR systems, while functional, still rely on laboratory testing and analysis of contaminants which can take more than 48 hours to receive a result, thus a breakthrough of contaminants from a treatment facility could potentially expose populations to harmful substances like bromate and NDMA, which are classified as potential carcinogens. Rather than waiting for a contamination breakthrough to arise and then responding, the utilization of online analyzers will enable timely detection and proactive intervention, thus protecting public health and confidence in DPR systems. The outcome of this study could demonstrate the ability to develop safer, reliable, and more affordable DPR systems, as well as addressing concerns about public safety.

Progress to Date

Work to Date

In the summer of 2022, the BAC and ozone systems were designed, fabricated, and constructed. Additionally, a UF-RO-UV AOP system was assembled and rigorous testing in the Ikehata Lab at Texas State University was done to ensure that the system was ready to be run in the field. The UF-RO-UV AOP system was deployed at the City of San Marcos Wastewater Treatment Plant in December 2022. After deploying, the system was run for a cumulative total of 116 hours throughout the spring 2023 semester and beginning of summer 2023. The RO system was operational for 77 hours due to recurring issues with the UF membranes. A microfiltration (MF) unit was added to the system increase the system flow rate. In the summer of 2023, the ozone and BAC skids were deployed to the wastewater treatment plant and testing is currently underway in preparation for running the ozone-BAC system with the final effluent (**Photograph 1**).

Photograph 1 – Complete AWP train deployed at the DPR Pilot Site at the City of San Marcos WWTP

Data Collection

In February 2023, an online bacterial counter XL-M4B was received from Rion Co. Ltd. (Kokubuji, Tokyo, Japan). The counter is unique in its capability to detect bacterial counts based on both particle size and auto fluorescence in real time. Dr. Takahiro Fujioka (Nagasaki University, Nagasaki, Japan) visited the laboratory at the same time and helped in setting up the bacterial counter. Over the spring semester, several laboratory tests were conducted comparing the bacterial counter's results with heterotrophic plate counts (HPC for Quanti-Tray, IDEXX Laboratories, Westbrook, Maine). The analysis focused on samples from multiple points in the treatment train: the final effluent of the WWTP (which was also the feed to our system), UF/MF feed, UF permeate, MF permeate, RO feed, RO permeate, and the UV-treated final product water. In May 2023, the analyzer was deployed to the pilot site, enabling real-time measurements (**Photograph 2**). In May 2023, the NDMA and bromate analyzers were received from Japan. The NDMA analyzer, developed by Dr. Hitoshi Kodamatani (Kagoshima University, Kagoshima, Japan) and marketed by Nichiri Manufacturing Co. Ltd. (Yachiyo, Chiba, Japan), uses high performance liquid chromatography and chemiluminescence to detect NDMA and other nitrosamines. The bromate analyzer, a prototype developed by Metawater Co. Ltd. (Tokyo, Japan), determines the concentration of bromate ion based on their reaction with trifluoperazine and the resulting fluorescence quenching. The analysis of the data from the bacterial analyzer is still in progress; however, preliminary results show some validation of the analyzers' performance against standard methods of bacterial enumeration.

Photograph 2 – Online monitoring system set up at the DPR pilot. RO Permeate is used as the dilution water for 0.2 mL/min of final effluent regulated by a pressure relief valve.

A total of 38 samples were tested using both a bacterial analyzer and HPC. These tests aimed to evaluate the efficacy of the analyzer and assess the comparability of the analyzer's results with those of the HPC testing. The bacterial content in final effluent, UF feed, UF permeate, MF permeate, and RO feed, exceeded the maximum bacterial count analysis capacity of the instrument, necessitating sample dilution. This was achieved using a peristaltic pump to introduce between 0.1 mL/min and 0.5 mL/min into a 3 mL/min flow of ultra-pure water with less than 100 counts/mL of bacteria. During the online monitoring phase, RO permeate water served as the dilution medium. However, mechanical issues with the pumps led to unstable flow distribution to the analyzer. To compensate, a flow rate monitor was used to log the flow and determine the average flow rate, which was then used to calculate the dilution factor and consequently the bacterial count.

Data Analysis

Figure 1a shows a comparison between the bacteria counts and HPC in the final effluent of the wastewater treatment plant. The Pearson correlation coefficient for bacteria counts and HPC in 38 samples was calculated to be 0.3234, and the *p*-value was 0.04767. This suggests a weak positive correlation between the bacterial analyzer and HPC testing. For bench-top analysis, the average time that the sample was analyzed through the bacterial analyzer was 30 minutes. For online analysis, the average time was 64.4 minutes. For online analysis, a longer sample time is desired, as results showed that the analyzer needed a considerable amount of time to achieve a "stable" result. During an 11-hour analysis of RO permeate through the bacterial analyzer, the analyzer reading appeared to continuously decrease as time moved on, however the reading never fully stabilized. Additionally, the sensitivity of the analyzer can be seen in the various spike events during this time, which are directly related to the opening and closing of sample port valves during sample collection (**Figure 1b**). The analyzer along with HPC testing was able to detect and show that there was log removal of bacteria counts throughout the MF-UF-RO-UV AOP AWP system.

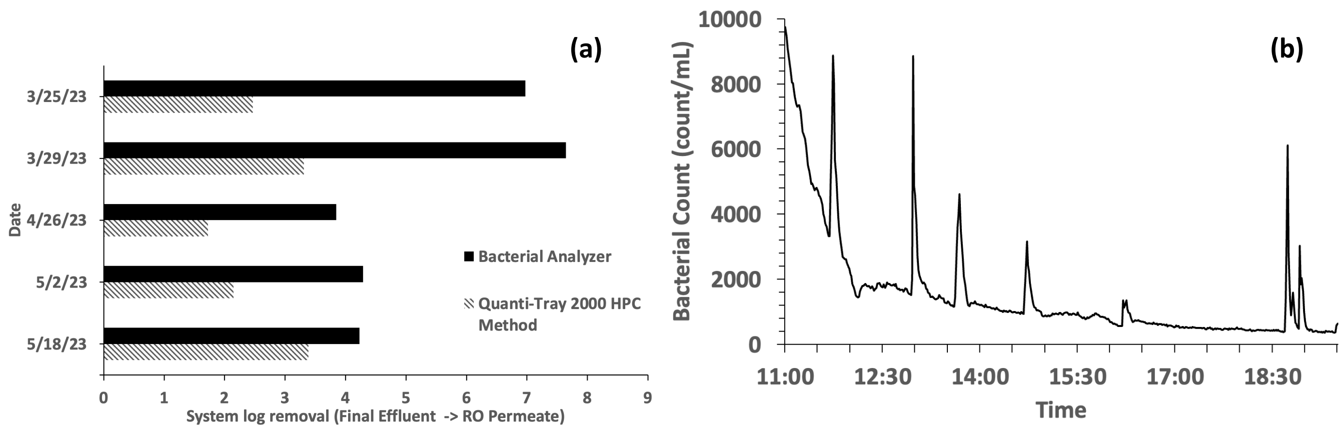

Figure 1 – (a) Comparison between the bacterial analyzer and HPC showing the readings of bacterial log removal from the City of San Marcos WWTP final effluent to the AWP Pilot RO permeate, **(b)** Online monitoring of RO permeate over an 8.5-hour period. Spikes are directly correlated to the opening and closing of sample ports.

Conclusions

The preliminary results from this study hold important implications for online real-time bacterial analysis in AWP system for DPR. Our data suggest that the bacterial analyzer can track the removal of bacteria throughout the various stages of the AWP treatment train, as well as the final product water. However, it is important to consider that the bacterial analyzer used in this study is designed for the pharmaceutical and semi-conductor industries, with the aim of ensuring that the water used in facilities from these industries is ultra-pure and sterile. For research to progress in this field, a bacterial analyzer must be designed and constructed specifically for an AWP treatment train. Online monitoring tools, like the bacterial analyzer tested, can streamline and enhance the monitoring process, offering real-time data that could improve decision-making and overall treatment efficacy. This possibility signals an advancement in the sector, shifting from traditional, time-consuming culture techniques (two days for Quanti-Tray) to more automated, real-time approaches.

Next Steps

My future research will focus on the NDMA and bromate analyzers. The primary objective will be to further evaluate and understand the analyzers' proficiency in our 2-GPM pilot and demonstrate their abilities to accurately detect and quantify NDMA and bromate levels in the pilot AWP system. One of the anticipated challenges that is foreseen is the complexity of simulating real-life wastewater treatment environments that can capture the wide array of conditions the analyzers may be exposed to in practice. Thus, there will be a development of practical ways to simulate situations that may result in a spike in bromate or NDMA, to test the robustness of the analyzers in these simulated scenarios. Additionally, to collect reliable, consistent data the pilot system must be able to continuously over a long period of time without any unexpected stops, pauses, or delays, much like a real-world AWP system would run. This requires careful planning to upgrade the system to a level where it can run autonomously and shut off on its own in the case of a leak or failure to prevent flooding and damage the system. With the inclusion of these systems, it may be possible to explore producing safe, drinkable water without the use of the RO process. RO systems are both costly and energy-intensive; however, they provide valuable log removal of bacteria and remove a broad spectrum of contaminants. Thus, being able to develop a safe DPR system using online analyzers as a safeguard to ensure clean drinking water without the use of an RO membrane can lead to a paradigm shift in the industry that can result in cheaper, cost effective DPR projects.