Introduction

Potable reuse is becoming an integral part of the water portfolio for many cities in arid western regions of the United States. Treatment processes, such as Full Advanced Treatment (FAT), using reverse osmosis (RO) and high energy UV advanced oxidation processes are being implemented in coastal communities where oceanic discharge of RO reject brine is available and permitted. For inland cities without realistic oceanic brine discharge options, the cost of disposing the brine stream is a major limitation to employing FAT technology. Although options exist for zero liquid discharge or deep well injection, these are expensive. More cost effective treatment options are needed and Ozone-Biological Activated Carbon (BAC) is on such alternative that is being considered by many inland water agencies. Ozone-BAC has the potential to produce a high quality effluent at a lower cost to FAT while avoiding the brine stream production and discharge issues that exist with FAT.

The project team has conducted studies (City of Reno, 2010) to investigate removal of 420 emerging and regulated contaminants across membrane filtration-ozone-BAC system. WRRF funded the sand filter-ozone-BAC testing portion of this project under **WRRF 08-05 Use of Ozone in Water Reclamation for Contaminant Oxidation**. This project demonstrated the effectiveness of Ozone-BAC treatment in removing a broad spectrum of contaminants of emerging concern (CECs) utilizing an empty bed contact time (EBCT) of 30 minutes. Findings from the Reno study indicated that reliable CEC removal equivalent to a FAT process train is more affordable than previously realized. A number of other WRRF funded studies (e.g. WRRF 11-02 - Equivalency of Advanced Treatment Trains for Potable Reuse, WRRF 13-10 - Controlling Trace Organic Contaminants Using Alternative, Non-FAT Technology for Indirect Potable Reuse, WRRF 13-09 Tucson Water Potable Reuse Project) are also ongoing.

To avoid duplication, we anticipate using these studies, as well as information gathered from an internet based collaborative workshop (see Task 1a), as a springboard to inform our experimental design for the objectives of this TC. The main goals are to fill data gaps within the ozone-BAC literature to allow regulators and designers to make informed decisions on its potential equivalence to FAT. Findings from this TC will be incorporated into a Guidance Manual to help facilitate ozone-BAC implementation without reliance on extensive pilot studies.The specific project objectives are highlighted below:

Project Objectives

- Establishing baseline relationship between ozone-BAC effluent TOC levels and Disinfection By Products (DBPs) or their formation potential
    - Examination of THM, HAA, nitrosamines, their precursors and microbial ecology of BAC.
- Pilot scale optimization of BAC to achieve maximum NDMA and flame retardant removal and characterization of organic constituents in the effluents.
- Development of a guidance manual for the potable reuse industry on operational optimization of ozone-BAC systems.

Research Approach

Task 1: Establish baseline relationship between ozone-BAC effluent TOC levels and DBPs and/or their formation potential

Task 1 will be divided into two subtasks. Task 1a focuses on an initial virtual workshop with participation from industry experts to ensure the project goals are aligned with the near future needs of the potable reuse industry. The workshop will be conducted with an expert workgroup as well as the Project Advisory Committee to identify critical information and data gaps, the team will then characterize and prioritize those data gaps.

Task 1a: Workshop to develop a framework for monitoring RO and BAC system performance

Objective: Conduct collaborative web based workshop to develop a framework for examining BAC operations in full scale systems

Task 1b: Examination of RO and BAC system performance

Objective: Establish baseline relationship between effluent quality and disinfection by products for full scale systems using RO membranes and ozone-BAC

Based on the intelligence gathered from a preliminary literature perusal and the virtual workshop, the current framework of utility sampling proposed in task 1b will be tweaked to better reflect the potable reuse industry needs.

Systems and Sampling Plan

A number of full scale systems across the US are employing RO membrane filtration or BAC treatment. A preliminary list of these systems has been developed for this project. Task 1b will focus on soliciting participation from a prioritized list of utilities and conducting a direct performance comparison between RO (n=3) and BAC (n=3) systems to define performance characteristics under various geographic, operational and seasonal variables.

For each system and treatment process, effluent samples will be collected over four quarters and analyzed for various water quality parameters, regulated and unregulated DBPs and DBP formation potential and microbial ecology to establish baseline values and variability in organics loading. For each system various operational parameters will also be recorded at the time of sample collection. As loading rates and operational characteristics will vary over time, it is estimated that four sampling campaigns will be conducted to help establish the baseline for operational and seasonal variability. Data gathered from Task 1b will establish the variability in effluent quality generated by RO systems and ozone BAC systems and will be used inform the experimental design for the pilot scale testing proposed in Task 2

Deliverables: Develop a baseline relationship between various parameters (i.e. water quality, operational and DBPs levels) and performance of RO and ozone-BAC systems. Characterize BAC performance with respect to microbial structure and function using Next Generation Sequencing.

Task 2: Pilot scale optimization of BAC

Objective: Pilot scale optimization of BAC to achieve nitrosamines and CECs (including flame retardants) removal and characterization of organic constituents in the effluents

Goals of pilot testing in Task 2 are as follow:

1. Determine optimum BAC design parameters (e.g. empty bed contact time [EBCT]) by evaluating its impact on:
    - Concentrations of DBPs in the effluent;
    - DBP formation potential of the effluent;
    - Emerging contaminant removal;
    - NDMA removal and/or formation; and
    - BAC microbial ecology
2. Improve understanding on the relationship between BAC analytical process monitoring (DOC removal, DO, effluent turbidity, etc.) and microbial ecology results (NGS, ATP, etc.)
3. Identify scenarios leading to undesired performance (e.g., denitrifying conditions and NDMA formation etc.) that can be potentially avoided via design and/or operation strategies
4. Evaluate potential nutrient limitations (micro and macro) and its impact on BAC performance

Description of the pilot

Based on project team's extensive knowledge on ozone-BAC systems, the following will be the basis of the pilot testing:

- Secondary Biological Process: Nitrification-Denitrification with min. 12 days SRT
- Ozone Dose: 0.75 – 1 mgO3/mg DOC
- Oxygen Source: Liquid Oxygen (LOX)
- BAC Media: GAC
- BAC Mode of Operation: Downflow
- Contact Time: Varies (time required to attain negligible dissolved ozone residual)
- Online monitoring: Gaseous ozone (feed gas and off gas), dissolved ozone residual, flow, pressure, UV transmittance, turbidity, dissolved oxygen, and BAC headloss.

Pilot Location, Setup, and Testing Duration

The project team has access to an ozone-BAC pilot system (shown here). The ozone unit includes liquid oxygen-fed ozone generator capable delivering 3 lb/d of ozone equipped with Mazzei ozone injectors and axial finned nozzle jets and a pipeline ozone contactor. The BAC pilot unit includes a stainless steel pressure vessel designed to operate in the downflow mode. This 3.5 ft-diameter vessel has been used previously with up to 1250 lbs of carbon, which has provided a media bed depth of 4.5 ft, EBCT varying from 10 - 30 minutes and, headspace > 50% of the bed depth to allow for bed expansion during backwashing. The BAC unit has sampling ports to allow for collection of carbon media samples at various depths from the media bed. The pilot study will be conducted over 9 months and will begin with natural development of the microbial ecology in the filtration media. That is, no microbial augmentation will be performed.

Some examples of operational parameters that will be investigated include:

Description	Unit	Value
Transferred Ozone Dose	mg O3/mg TOC	0.75 – 1
Flowrate	gpm	10 – 50
EBCT	Min	10 – 30
Loading Rate	gpm/sf	1 – 3

The impact of these design/operational variables on system performance will be monitored using the suite of analyses (TOC, AOC, THMs, HAA, nitrosamines, DBP formation potential, SUVA, media microbial ecology) described in Task 1b. Additionally, selected indicator CECs, including TCEP, TCPP and TDCPP, will be monitored.

Deliverables: Pilot studies to establish relationship between various operational and water quality parameters in ozone-BAC system

Task 3: Development of a guidance manual for BAC systems

Objective: Guidance manual for potable reuse industry on operational optimization of BAC systems

Comprehensive guidelines for applying, designing, and operating ozone-BAC technology in wastewater applications are unavailable. The various case studies and demonstration projects reveal what has and has not worked in specific situations. Regulators, engineers and operators have no general reference on the subject of wastewater ozone-BAC technology. The project team proposes to draft a guidance manual. The final arrangement of the manual will depend on input from our project partners, the project advisory committee, expert solicitation from the workshop and other appropriate peer reviewers, but the manual will contain at least the following sections:

Introduction: Discusses concepts of ozone-BAC treatment in the contexts of potable reuse projects, regulations, public perception, case studies, and alternative technologies. This section is expected to provide a water supply planner, designer, and/or operator with sufficient information to understand conceptually the ozone-BAC technology and form an opinion as to whether ozone-BAC warrants further study for a specific situation under consideration.

Treatment and Performance Requirements: This section will discusses how ozone-BAC works and what range in performance may be expected. To the extent possible, this section is about the science behind the engineering, which follows.

Engineering: This section includes: 1) Pretreatment Requirements, 2) Ozone, 3) BAC) and 4) Post-Treatment Requirements.

Operation and Maintenance: This section discusses the day-to-day operation and maintenance of an ozone-BAC system. This section will also include a discussion of recommend microbial and analytical monitoring, anticipated problems and solutions, a trouble-shooting guide, other recommendations on process monitoring, etc.

Deliverables: Development and dissemination of a guidance manual through various outreach efforts (webinar, conferences and publications)

Task 4 Prepare final report

Objective: Prepare a final report in the form of a user-friendly guidance manual and standard report according to WRRF guidelines

The project team will prepare the final report to include a detailed discussion of the workshop deliberations (Task 1a), the rationale for developing the plan in Task 1b for full scale RO system and ozone-BAC systems, identification of the prioritized parameters following statistical analyses of data in Task 1b and validation of key drivers in the pilot scale studies (Task 2).
Because the project team consists of industry practitioners, the team feels the potable reuse industry would be best served by guidance document on BAC optimization strategies. We plan to include such guidance as a stand-alone document and in the report to help ensure that the project outcome will have an action-oriented