Incorporating Ferrate Oxidation into Small Drinking Water Systems

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Abstract
Ferrate has been studied in bench-scale and small continuous-flow pilot-scale systems in an effort to better understand its role within a conventional water treatment system. A wide range of disinfection byproducts (DBPs) were monitored, as well as secondary oxidants. This work shows that ferrate can be incorporated into conventional water treatment for the purpose of meeting multiple objectives (e.g., DBP precursor control, disinfection, Fe & Mn control, micropollutant removal), while not adversely impacting clarification or filtration performance.

Keywords
Ferrate, oxidation, disinfection, disinfection byproducts

BACKGROUND AND OBJECTIVES
Ferrate is a strong oxidant and disinfectant that has long been proposed for use in drinking water systems (e.g., Graham et al., 2010; Ma & Liu, 2002; Sharma et al., 2005). This compound has been the subject of much laboratory research and results to date show it to be very effective at oxidizing a wide range of trace contaminants in water. Despite more than a decade of careful study and dozens of highly-regarded publications, ferrate still has not been accepted by the municipal water suppliers. In our view this can be attributed to three factors: (1) the cost and supply of ferrate is still not well established, (2) the regulatory credit for ferrate as a disinfectant has not yet been published, and (3) the overall impact of ferrate treatment on potable water systems operating under multiple treatment objectives has not been fully explored.

The purpose of this study is to determine the roles and impacts of ferrate within a typical water treatment train. This is being done with a small systems focus. The treatment objectives that are under study include: removal of natural organic matter, removal of turbidity, disinfection, control of disinfection byproducts, removal of iron and manganese, as well as oxidation of a wide range of inorganic contaminants and trace organic compounds. This work includes assessment of residuals, energy, features of special concern to small systems (e.g., ease of operation, training requirements, and reliance on supply chains), and a life cycle analysis.

MATERIALS AND METHODS
These studies were conducted in the laboratory at UMass in both batch and continuous flow mode. Ferrate was added in the form of a high-purity (~98%) potassium ferrate (K_2FeO_4) salt. Residual ferrate was measure using the ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonate)) method (Lee et al., 2005). The production of the secondary oxidants, H_2O_2 and OH radicals were determined with horseradish peroxide and p-chlorobenzoic acid (Lee et al., 2014). Total and dissolved organic carbon (TOC and DOC), trihalomethanes, and haloacetic acids were determined in accordance with standard protocols (APHA et al., 2012).

RESULTS
In this paper we will present the results of 3 years of bench-scale and small pilot-scale treatment using

ferrate as both a pre-oxidant and an intermediate oxidant. With these data we will show that ferrate behaves much like ozone in its ability to oxidize disinfection byproduct (DBP) precursors, such as those that form trihalomethanes (THMs) (Figure 1). We will also show that much of the benefit in precursor destruction is lost when ferrate is applied as a pre-oxidant, but not when used as an intermediate oxidant. Finally, we will show from continuous-flow pilot studies that ferrate can be incorporated into a conventional treatment train without adversely affecting clarification and filtration performance.

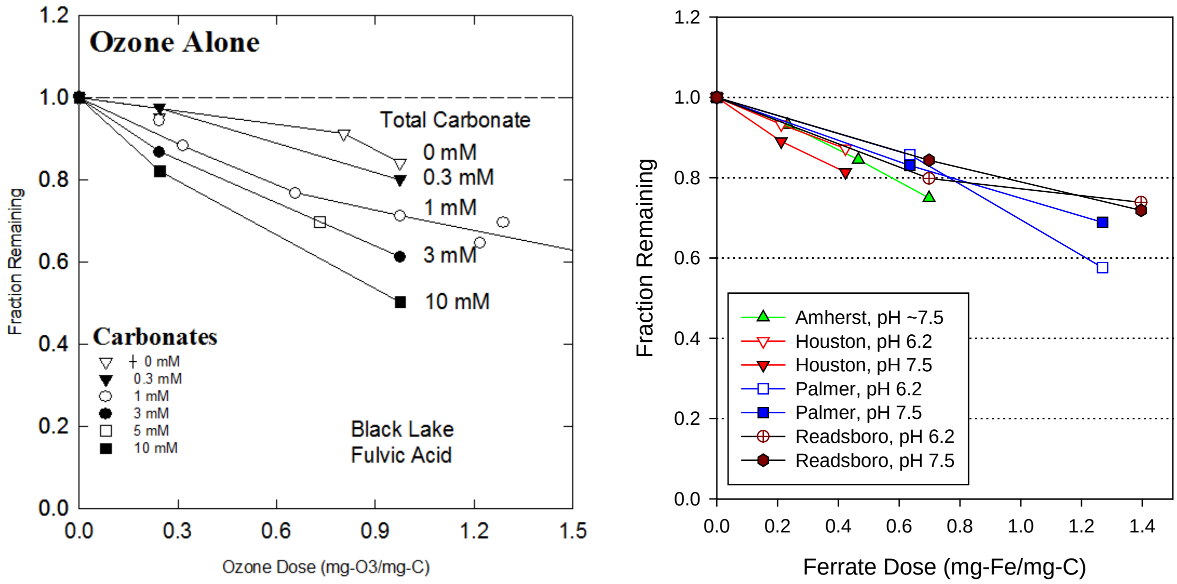

Figure 1. Comparison between ozone and ferrate for oxidation of THM precursors.

CONCLUSIONS

Ferrate can bring to small water systems many of the benefits of ozonation but without the high capital costs and complex operation. Aside from its effectiveness as a disinfectant and oxidant for micropollutants, it can also result in substantial and targeted removal of DBP precursor structures in natural organic matter. It appears to be especially effective at controlling DBPs when used as an intermediate oxidant (between clarification and filtration) and there are no signs that its use creates substantial impacts on filter performance or run length.

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