Environmental Study on Urban Disinfection using an On-site Generation System

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Abstract

In this experimental study, the behavior of Mixed Oxidant solution components (MOS) and sodium hypochlorite (HYPO) as the most commonly applied surface disinfectant were compared through the effectiveness of chlorine disinfection as a function of the contact time and residual chlorine. In this regard, the variation of pH, free available chlorine (FAC) concentration, and electric conductivity (EC) of disinfection solutions in different concentrations were monitored over 48h contact time. In parallel, the plant stress activated by chlorine-based disinfectants was assessed by comparing MOS and sodium hypochlorite. The elements of pH and electric conductivity (EC) in the plant-soil and their environmental impacts, spread by disinfection solutions were analyzed through several concentrations of FAC including 500, 1000, and 5000 mg/L in irrigated water. All the experiments were carried out at the service station of Sant Cugat, Spain. The outcomes indicated lower pH and higher durability of MOS than sodium hypochlorite at the same concentration of FAC which resulted in promising stability of FAC within MOS. Furthermore, the pH and EC value of plant-soil irrigated by NaOCl solution were higher than that of MOS solution at the same FAC concentration. On-site generation of MOS as a safe chlorination option might be considered an imaginary future of smart cities.

Keywords— Disinfection, Free available chlorine (FAC), On-site generation, Sodium hypochlorite.

I. Introduction

NOWADAYS with regard to safety concerns, liquid chlorine compounds such as sodium hypochlorite are used instead of chlorine gas for different applications. The commonly available chlorine in Sodium hypochlorite (NaOCl) at concentrations between 5 and 15% is operated in liquid form. An alternate technique is the on-site generation of NaOCl, which is achieved through electrolysis by applying an electrical current to a solution of salt and water. The reported value for minimum chlorine residuals varies between 1 ppm and 1.8 ppm depending on pH and contact time for bactericidal disinfection. Considering 30 min of contact time, a hypochlorous residual of 0.5–1.0 ppm is applicable. The contact time and chlorine residual concentration play key roles in the effectiveness of chlorine disinfection. As reported, the solubility of Chlorine gas in water (7160 mg/L at 20 °C and 1 bar), and then hypochlorous acid rapidly is formed by hydrolyses. Increasing pH declines the power of free chlorine residuals. Hypochlorous acid concentration at 20°C decreases from 90% to 10% at pH 7 to pH 8.6, respectively [1]. Hence, automatic monitoring of residual chlorine and automatic feedback of the injection rate is necessary to prevent over-dosage or inadequate disinfection from an environmental and economical point of view.

In this regard, the practical stability of BACO solution and sodium hypochlorite in terms of FAC at different contact times is concerned in the current report. Different concentration ranges including 500, 1000, and 5000 ppm of both MOS and Hypo solutions were taken into account during 48h.

II. Procedure and Method

The proposed work is tabulated in Table 1. The BACO solution (MOS) was a transparent disinfectant liquid consisting of FAC concentration of 0.8% and pH > 9. On the other hand, sodium hypochlorite containing FAC concentration of 11.5% and pH > 12 was purchased. All solutions were prepared with pre-distilled 5 μS/cm deionized water. Six beakers were set up as containers with different materials including pyrex, metal, and plastic. The DPD (N, N-diethyl-p phenylenediamine) method based on the International Organization for Standardization (ISO) Method 7393/2 for residual chlorine was adopted for FAC measurements.

TABLE 1
THE PROPOSED STUDY

Subject	Type	FAC (ppm)	Residual species	Timing
Disinfection	MOS	500	- FAC - pH - EC (*Electric conductivity*) - TDS (*total dissolved solids)*	- Initial - 1 h - 48 h
		1000		
		5000		
	Sodium Hypochlorite	500		
		1000		
		5000		
	Control	0		

III. Result and Discussion

A. Solution Stability of MOS and HYPO

Based on the data of experiments, the efficacy of MOS was compared with that of NaOCl at equivalent free chlorine concentrations of up to 5000 mg/L. Disinfectant residuals behave differently on different surfaces. In this regard, 3 different materials were studied through the experiments.

As can be tracked through Fig. 1 from (a to c), the amount of residual FAC for both solutions MOS and sodium hypochlorite were decreased after 48h as expected. However, all cases except

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A(5000 ppm) indicated higher residual FAC of MOS than sodium hypochlorite which resulted in promising stability of FAC within MOS. The FAC trend might be justified by its interaction effect with pH. The significant role of pH is related to the dissociation of HOCl, which in turn regulates the effectiveness of disinfection. For pH range 3–5, chlorine remains as HOCl and for pH <3, it remains as CL_2 chlorine remains as HOCl and OCl^- in the pH range 5–10, and beyond a pH of 10.0, chlorine remains in the form OCl^- It should be noted that HOCl is the strongest disinfectant of all the different chloride species. Hydrogen and chlorine ions have no disinfection properties [2]. The experimental results in this study illustrated higher pH at the same concentration of FAC in sodium hypochlorite than MOS that may justify the promising FAC stability of MOS. HOCl with strong disinfection properties despite the fact that OCl^- is a weak disinfectant, calls attention to the reaction conditions to be so maintained through the formation of favored HOCl while that of OCl^- is discouraged. The chlorine-based disinfection at lower pH is favorable as a result of a higher amount of HOCl.

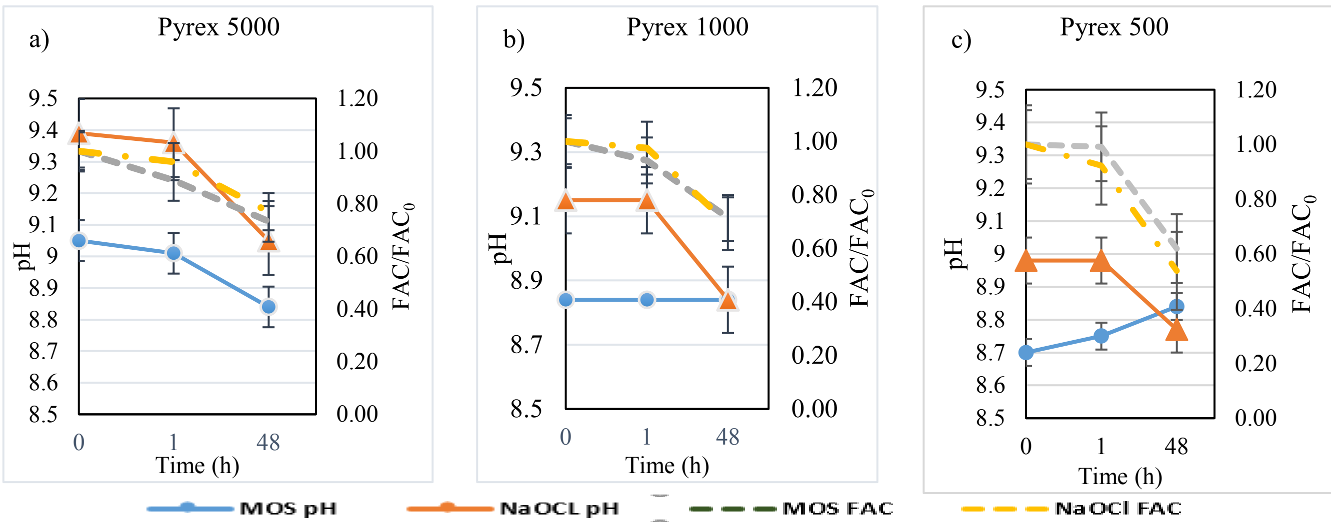

Fig. 1 Variation of pH and FAC over time for MOS & HYPO solution a) 5000 ppm, b) 1000 ppm, c) 500 ppm, (solid line for pH, dotted line for FAC)

High pH values favor the formation of OCl^-, the less effective free residual form. The OCl^- initiates to dominate and the time involved for the free residual to effectively disinfect increases as pH rises from 7.0 to 10.7. This effect diminishes in the pH range 7.0–8.5 but beyond a pH greater than 8.5 significantly escalates the disinfection time [2].

When compared with chlorine as gas or as hypochlorite, the mixed-oxidant solution has been shown consistently to achieve a greater inactivation of microbial contamination at faster rates in a wider range of water (pH and temperature) conditions [3]. The disinfectant residual cannot be maintained at high levels because the strong chlorinous taste of the water would result in customer complaints to water companies. High chlorine residuals also promote the formation of trihalomethanes (THMs) which some studies have shown to be carcinogenic at high levels in the mg/L range. Current regulations require that THM concentrations should not exceed 100 µmUg/l [4].

B. Effect of MOS and HYPO in Soil

In this study, plant stress activated by chlorine-based disinfectants was assessed by comparing BACO multi oxidant solution (MOS) and sodium hypochlorite (HYPO). Chlorine deficiency appears along leaves margins and tips, leaves are smaller than usual and plant growth is also reduced [5].

The absorbed elements of Cl, pH, and electric conductivity (EC) in the plant-soil and their environmental impacts, spread by disinfection solutions were analyzed through different concentrations of free available chlorine (FAC) including 500, 1000, and 5000 ppm in irrigated water. The experimental assay consists of applying the irrigation and sprayed disinfection solutions on the soil surface of the 21 flower pots.

Fig. 2 shows the pH and EC of the soil subsamples collected at different days of experiments. The soil pH in all concentration of FAC increased or kept constant compared to the initial value, which is due to the formation and transport of H^+ and OH^- ions. Nevertheless, in most of the sampling data, the pH value of soil content irrigated by HYPO was higher than MOS that can be due to the higher pH of NaOCl solution than MOS used for watering. Soil EC after the irrigation fluctuated compared to the initial conditions shown in Fig. 2. It is ascribed to the transport of ions from water solution into the soil. The soil EC values in the 5000 ppm samples were higher than that of 1000 ppm and 500 ppm, respectively. This tendency was in accordance with the change of FAC in the watering solution. However, the behaviors were different in most of the cases as the conductivity fluctuated.

The plants' appearance during experiments were deformed sharply until drying out with respect to the corresponding FAC concentration. In the other words, the higher concentration of FAC, the sooner drying out of the plant. Further tests are required for developing the reported study.

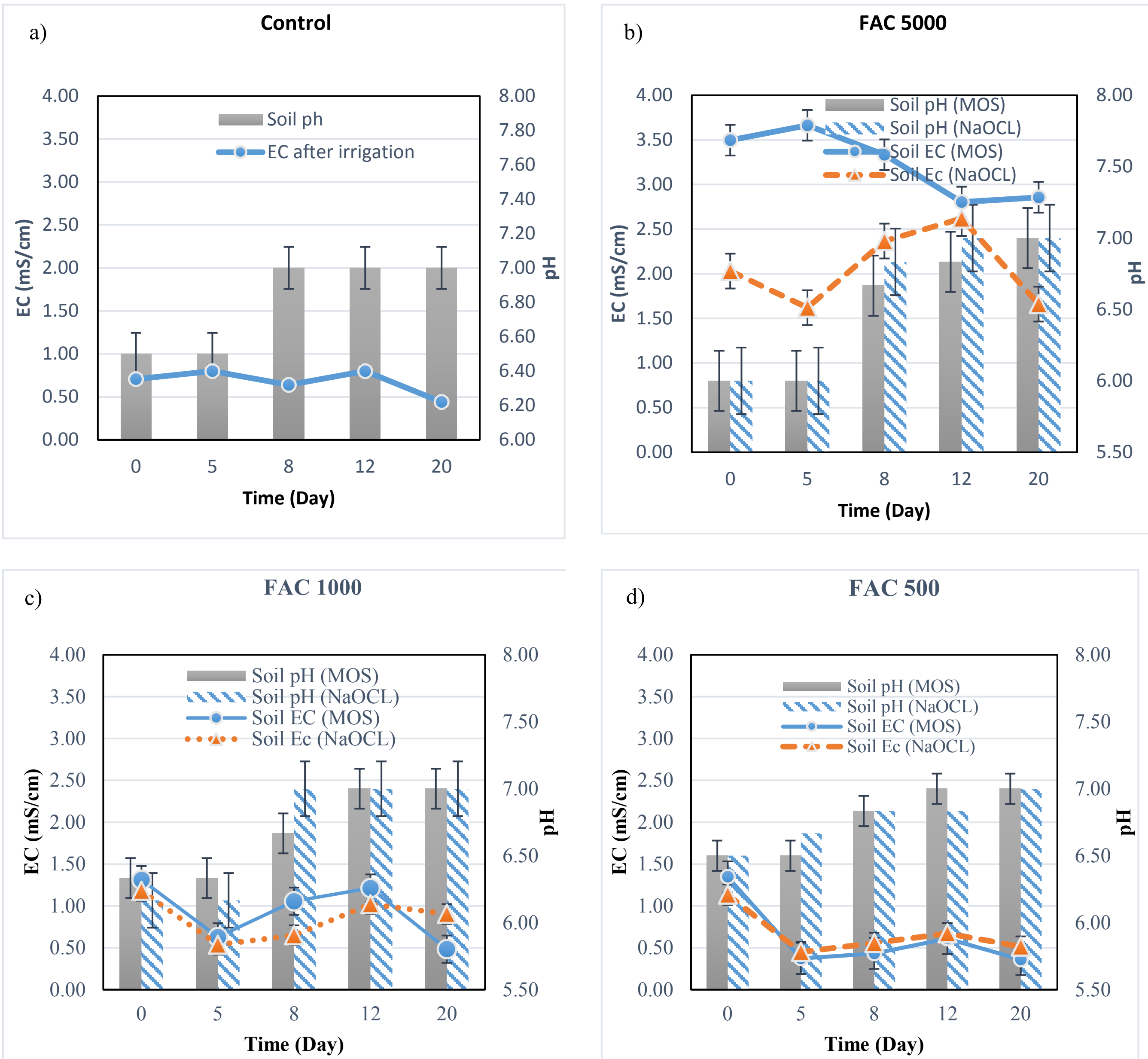

Fig. 1 Variation of pH and EC during 20 days in the soil of plants watering by a) Control (tap water), b) FAC=5000 ppm, c) FAC=1000 ppm, and d) FAC=500 ppm

C. Environmental Impacts of On-Site Hypochlorite Generation (MOS) vs HYPO

Typically, the pH of oxidant solutions is in the range of 8 - 10. Dosing water with MOS produced oxidant solutions often does not alter the pH of the water being treated since the produced oxidant solution is used at a volume ratio of at most 1:1000 with the water to be treated under most application scenarios.

To sum up, the presented method of on-site MOS generation is the most sensible option when considering safety, economic, and environmental issues for the following reasons:

- It is a safe chlorination option. It is the safest chlorine-based water disinfection option. Indeed, the only chemical to be used and stored in bulk is salt. Also, generation takes place in an isolated system. It is a clinically clean process with no dripping, mixture of, or exposure to chemicals or fumes. The only by-product, hydrogen, is safely vented into the atmosphere or it can be diluted below 4 mol% to prevent any issues with flammability.
- The generated hypo is classified as a non-hazardous chemical (0.8% concentration) as compared to commercial hypo at 14%. It should be noted that hypo above 1%is classified as a hazardous chemical.
- It is generated on demand, thus no bulk storage (a unique safety feature).

- It contributes to workplace and general public safety as bulk transport, bulk storage, and bulk handling of potentially hazardous chemicals (gaseous chlorine and commercial hypo) are totally eliminated.

V. Conclusion

The differences in MOS from those of sodium hypochlorite are clear and well documented. As a result of these differences, MOS mixed-oxidant solution can be used to address water quality issues that hypochlorite, and indeed other oxidant disinfectants as well, simply cannot. Although pH was declined over time, the pH of NaOCl solution is higher than the pH of the MOS solution at the same FAC concentration. MOS indicated regular stability of FAC and further study will be required in this process.

The experiments with the plants confirmed that chlorine ions are generally toxic to plants' growth at relatively low concentrations and may cause irreversible damage to their development. From the obtained results, it can be concluded that while plant growth was reduced in the presence of chlorine from all tested compounds, the pH and EC value of plants soil irrigated by NaOCl solution was higher than that of MOS solution at the same FAC concentration. The plants watered by higher FAC concentration were drying out faster.

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