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Primary concerns regarding the application of electrolyzed water in the meat industry

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ABSTRACT

The application of electrolyzed water effectively reduces microbial contamination and has greatly contributed to delayed meat spoilage. However, concerns about applying electrolyzed water in the meat industry, which include the stability of available chlorine in various storage conditions, corrosion resistance and residual chlorate, have attracted much attention. In this study, primary concerns regarding acid electrolyzed water (AEW) and slightly acid electrolyzed water (sAEW) were evaluated in comparison to those of sodium hypochlorite (SH) widely used in meat processing plants. The results showed that closed and 4 °C storage conditions, which just declined about 30% ACC of available chlorine concentration (ACC), were more beneficial than open and 20 °C storage conditions for maintaining the stability of electrolyzed water, whereas no differences in stability were observed between dark and light storage. The decline of ACC positively depended on the concentrations of organic materials ranged from 0.1% to 0.3%, and the ACC was close to 10 mg/mL after 30 min trearment. The corrosion of AEW was equal to that of SH, but it was higher than that of sAEW. In addition, the concentration of residual chlorate in meat sprayed by electrolyzed water was less than meat sprayed by SH. The findings suggested that electrolyzed water is a great potential substitute for SH in the meat industry.

1. Introduction

Microbial contamination is a widespread public concern in the meat industry because it can shorten the shelf life and increase the safety risk of fresh meat and meat products. For both managers and consumers, reducing microbial contamination during animal slaughter is imperative for avoiding economic losses and health concerns (Patsias, Chouliara, Paleologos, Savvaidis, & Kontominas, 2006; Petrou, Tsiraki, Giatrakou, & Savvaidis, 2012). Chlorine-based decontamination disinfectants, such as sodium hypochlorite (SH) and chlorine dioxide, are the most commonly used interventions in animal slaughter plants due to their antimicrobial efficacy, convenience and low price (Ban & Kang, 2016; Duan, Wang, Xue, Li, & Xu, 2017; Visvalingam & Holley, 2018). However, some previous studies have warned users about the limited efficacy of chlorine for microorganism reduction on meat and meat-contacted surfaces (Cai et al., 2018; Killinger, Kannan, Bary, & Cogger, 2010; Park, Chung, & Ha, 2018). More importantly, toxic chlorination by-products, mainly including chloroform, trihalomethanes and haloacetic acids, have been observed in cheese and beverages, which was originated from the disinfectants used in the industry to clean and sanitize all contact surfaces and processing equipment, and formation during food manufacturing process due to reactions between chlorine residuals and precursors present in foods (carbohydrates, lipids and proteins) (Cardador, Gallego, Cabezas, & Fernández-Salguero, 2016); It has also been demonstrated that sodium hypochlorite used as a disinfectant could react with organic materials to produce chloroform (Waters & Hung, 2014). The potential health risk of chlorination by-products to consumers includes an increased cancer risk, spontaneous abortions and birth defects according to warnings from the World Health Organization (WHO). The discovery for alternative disinfectants for meat and poultry decontamination is ongoing due to the drawbacks of traditional chlorine-based disinfectants.

Electrolyzed water has been widely recommended as a substitute disinfectant for SH, due to its strong bactericidal effects on various dominant spoilage and pathogen microorganisms, such as *Salmonella*, *Escherichia coli*, and *Shewanella* (Gómez-López, Gil, Pupunat, & Allende, 2015; Han, Hung, & Wang, 2018). In fact, electrolyzed water is typically used in two forms: acid electrolyzed water (AEW) and slightly acid electrolyzed water (sAEW). A diluted salt solution is passed through an electrolytic cell with a membrane divider between the two electrodes, and AEW is generated in the anode at a low pH, high oxidation reduction potential (ORP) and a high available chlorine concentration

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(ACC). sAEW is another form of electrolyzed water with a higher pH, lower ORP and lower ACC than AEW, and it is generated by passing diluted NaCl or HCl solutions through an electrolytic cell without a membrane between the two electrodes. The simplicity of the production procedure, convenient industrial application, efficient antimicrobial activity and cost-effectiveness of electrolyzed water have promoted its utilization (Gil, Gómez-López, Hung, & Allende, 2015; Rahman, Khan, & Oh, 2016). In particular, previous works have demonstrated that the application of AEW and sAEW in either a laboratory setting or large-scale chicken slaughter plants could not only reduce the initial microbial load but also extend the shelf life of chicken carcasses (Duan et al., 2017; Wang et al., 2017). However, little information has been published regarding the primary concerns of electrolyzed water in its practical application, including the stability of available chlorine during various storage conditions, corrosion resistance and residual chlorate. The ACC stability of electrolyzed water during storage conditions and in the presence of organic materials is closely correlated to its decontamination effects (Oomori, Oka, Inuta, & Arata, 2005; Xuan et al., 2016). Although it is recommended that electrolyzed water is used immediately after its preparation to obtain maximum bacterial effects, it is sometimes unavoidable to store the water for a period of time (Nagamatsu, Chen, Tajima, Kakigawa, & Kozono, 2002). Many studies recommend utilizing electrolyzed water without organic compounds as an optimal treatment condition (Chen & Hung, 2017). However, this condition is an ideal scenario as organic compounds exist extensively in meat slaughtering scenarios. For example, although fresh water is continuously poured into the chiller tank in the chicken slaughter line, an increase in various organic compounds from carcasses can be clearly observed. The presence of organic materials could lead to the degradation and undesired consumption of ACC, directly resulting in an ACC decrease and weakening decontamination effectiveness. Therefore, it is of great significance to evaluate ACC changes during different storage conditions and in the presence of organic materials.

The corrosion of metals caused by the application of electrolyzed water is a potential concern because of the existence of corrosion-induced factors, such as low pH and Cl^-, ClO^- and other oxidizing agents (Ayebah & Hung, 2005; Han et al., 2017). Many devices and pieces of equipment exist in animal slaughter plants, and these items are commonly produced out of various metals. Corrosion can damage equipment precision and directly increase operating costs at slaughter plants. In addition, the corrosion that occurs on meat-contacted surfaces can form a pit or a crack, which can protect bacteria from water-washing or decontamination (Haibo Wang et al., 2014; Haibo Wang, Hu, Zhang, Liu, & Xing, 2018); these surviving bacteria may result in the cross-contamination of microorganisms. An evaluation of the corrosiveness of electrolyzed water on various metals commonly used in animal slaughter plants is therefore critical and could help avoid unnecessary losses.

Residual chlorate is another potential safety concern since the European Food Safety Authority (EFSA) concluded that the chlorate that appears in food mainly arises from the use of chlorine-based disinfectants, such as sprays or dipping solutions for meats, vegetables, fruits and seafood, and from poultry chilling water (Kettlitz et al., 2016). Chlorate exhibits toxicity and may damage the liver, kidney, intestine and other organs (Ali, Ansari, Khan, & Mahmood, 2017). Negative neurological and hematological effects were also observed in infants who consumed high levels of chlorate-contaminated water. The WHO recommends 0.7 mg/L as a guideline for chlorate levels in potable water, and EFSA published an opinion on the chronic and acute public health risks from dietary exposure to chlorate, deriving a tolerable daily intake of 0.003 mg chlorate/kg body weight and an acute reference dose of 0.036 mg/kg body weight (EFSA, 2015; WHO, 2011). Thus, monitoring the levels of residual chlorate in the application of electrolyzed water is an urgent issue.

Therefore, the objectives of this study were 1) to investigate the effects of storage conditions and organic loads on the stability of electrolyzed water and 2) to determine potential metal corrosion and residual chlorate in meat when electrolyzed water is applied in animal slaughter plants.

2. Material and methods

2.1. Disinfectant preparation

AEW was generated using an Electrolyzed Water Generator (XL-150, Baoji Xinyu Optics-Mechanics-Electricity Co., Ltd. Baoji, China) containing positively charged and negatively charged electrodes separated by a bipolar membrane. A salt solution (5% NaCl) and deionized water were pumped into the water generator, and AEW with a pH of 2.52, ORP of 1168 mV and ACC of 61 mg/L was produced in the anode chamber. sAEW with a pH of 6.21, ORP of 862 mV, and ACC of 30 mg/L was generated by electrolysis of an aqueous mixture containing 1.0% HCl and 1.5% NaCl solutions using another Electrolyzed Water Generator (CE7300-30, Guangzhou Saiai Environmental Protection Technology Development Co., Ltd. Guangzhou, China), which was equipped with an electrolytic cell without a separating membrane between the anode and cathode electrodes. Approximately 100 mg/L of SH was prepared by diluting chlorinated water with deionized water to produce the appropriate concentration. The pH and ORP values of the disinfectants were measured using a dual scale pH/ORP meter (PB-10, Sartorius Co., Germany) bearing a pH electrode and an ORP electrode. ACC was measured by a colorimetric method using a digital chlorine test kit (Chlormeter Duo, Palintest Co., UK) with a detection range of 0–250 mg/L.

2.2. Storage stability

Changes in the ACC of AEW and sAEW under 8 different storage conditions, including closed-dark-20 °C, closed-light-20 °C, closed-dark-4°C, closed-light-4°C, open-dark-20 °C, open-light-20 °C, open-dark-4°C, and open-light-4°C, were determined after storage for 0, 2, 4, 6, 8 and 10 days. Two-liter transparent and dark-brown glass jars were respectively used as containers for AEW and sAEW to achieve different light conditions. A fluorescent light at 480 lux was used as the light source to simulate the general light conditions of a chicken slaughter line (usually 350–750 lux) (Len et al., 2002). The open and closed glass jars were stored in 4 °C and 20 °C incubators, respectively, to maintain a constant storage temperature during the storage period.

2.3. The effects of organic materials on ACC

Mixtures of chicken skin (20%) and meat (80%) were used at concentrations of 0.1%, 0.3% and 0.5%. These values were selected to approximate the different residual organic material levels in a water chiller tank during chicken slaughter. Chicken skin and meat samples were cut into small pieces using scissors, and 1 g, 3 g and 5 g mixes of skin and meat pieces were then immersed into 1000 mL of disinfectants. The changes in the ACC of AEW and sAEW were measured every 10 min over a range 0–60 min since bactericidal treatment usually lasts for approximately 10–30 min in an actual chicken slaughter line.

2.4. Corrosion assays

Corrosion assays used 304 stainless steel, aluminum, copper and carbon steel. Tests were conducted according to the "Disinfectant Technology Standard" issued by the China Ministry of Health, 2008 edition. The specification of the metal sheet for the corrosion test was 24 mm in diameter and 1 mm in thickness with a 2-mm diameter hole in the core. All metal sheets were immersed in a mild nonbleach cleaner for 10 min to wash off the oil and were then polished with abrasive paper to remove the metal oxide film on the surrounding surface. After the sheets were thoroughly rinsed with deionized water, they were