Development of Portable Flow-Through Electrochemical Sanitizing Unit to Generate Near Neutral Electrolyzed Water

Jufang Zhang, Hongshun Yang, and Joel Zhi Yang Chan

Abstract: We developed a portable flow-through, electrochemical sanitizing unit to produce near neutral pH electrolyzed water (producing NEW). Two methods of redirecting cathode yields back to the anode chamber and redirecting anode yields the cathode chamber were used. The NEW yields were evaluated, including: free available chlorine (FAC), oxidation-reduction potential (ORP), and pH. The performances of 2 electrodes (RuO$_2_-IrO_2_/TiO_2$ and IrO$_2_-Ta_2O_5_/TiO_2$) were investigated. The unit produced NEW at pH 6.46 to 7.17, an ORP of 805.5 to 895.8 mV, and FAC of 3.7 to 82.0 mg/L. The NEW produced by redirecting cathode yields had stronger bactericidal effects than the NEW produced by redirecting anode yields or NEW produced by mixing the commercial unit’s anode and cathode product ($P < 0.05$). Electron spin resonance results showed hydroxyl free radicals and superoxide anion free radicals were present in the NEW produced by developed unit. The NEW generator is a promising sanitizing unit for consumers and the food industry to control foodborne pathogens.

Keywords: Escherichia coli O157:H7, free radical, Listeria monocytogenes, safety, sanitization

Practical Application: Current commercial NEW-producing units are quite large and are not convenient for family using. The developed portable flow-through, NEW-producing unit has great potential in a wide range of applications, such as organic farm, households, and small food industries. The examined sanitizing treatments showed effective control of Escherichia coli O157:H7 and Listeria monocytogenes.

Introduction

Adequate sanitizing treatments should be applied during the processing and preparation of foods in family kitchens and in the food industry. Recently, the consumption of organic foods has increased worldwide (Yu, & Yang, 2017). U.S. regulations have established that some sanitizing agents are permitted to process organic foods and equipment. However, these chemical sanitizers have limited availability and sanitizing effects (Zhang, & Yang, 2017). Therefore, it is important to develop sanitizers that are suitable for family kitchens and the food industry, especially organic food industry.

Electrolyzed water (EW) has been approved as a food sanitizer by the Food and Drug Administration (Hsu, 2003, 2005; Huang, Hung, Hsu, Huang, & Hwang, 2008; Liu, Tan, Yang, & Wang, 2017a; Liu, Wu, Lim, Yang, & Wang, 2017b; Park, Guo, Rahman, Ahn, & Oh, 2009; Zhang, & Yang, 2017; Zhang, Zhou, Chen, & Yang, 2017). It has been reported to possess antimicrobial activity against a variety of microorganisms (Hao et al., 2012; Huang et al., 2008; Liu et al., 2017a; Pang, & Hung, 2016; Sow, Tirtawinata, Yang, Shao, & Wang, 2017; Zhang, Li, Jidea, & Hung, 2016). However, at low pH, EW is corrosive, has a short shelf life, might be toxic to operators, and cause corrosion of different types of metals. A feasible solution is the use of a nearly neutral EW (NEW; pH 6.0 to 7.5; Ayebah, and Hung, 2005; Cao, Zhu, Shi, Wang, & Li, 2009; Gil, Gómez-López, Hung, & Allende, 2015; Len, Hung, Erickson, & Kim, 2000; Waters, Tatum, & Hung, 2014; Xuan et al., 2016).

In general, NEW is produced by mixing the catholyte with EW produced by a divided electrolytic cell, with diluted NaCl solution as the electrolyte (Yang, Feirtag, & Diez-Gonzalez, 2013; Zhao, Zhang, & Yang, 2017). With same electrolyte, another method to produce NEW involves using 3 tubs with 2-membrane partitions and 4 sheets of electrodes in the electrolytic cells (Umimoto, Fujiwara, Nagata, & Yanagida, 2013). Additionally, NEW can be produced by electrolysis of hydrochloric acid (HCl) or diluted NaCl solution in a nonflow-through undivided electrolytic cell (Cao et al., 2009). Some NEW is produced using a developed circulating EW generating system with an undivided electrolytic cell using a NaCl/HCl solution (Xuan et al., 2016). However, an undivided electrolytic cell is limited by cell resistance, which results in low-current and low-power efficiencies, and at the same time, introduces rapid chlorate accumulation from the electrolysis of stagnant electrolytes (Grinberg, Skundin, & Tuseeva, 2001; Nath, Wang, Torrens, & Langdon, 2011).

There are some reports of the continuous production of NEW using a commercial electrolysis unit (Gil et al., 2015; Guentzel, Lam, Callan, Emmons, & Dunham, 2008; Zhao et al., 2012; Munnin, Lee, & Pascall, 2012). However, these current commercial NEW-producing units are quite large and are not convenient for households and small food industries (Yang et al., 2013).
A portable, user-friendly NEW generator is necessary to meet market demand and improve food safety. In our previous study, we developed an electrolytic sanitizing unit that can produce NEW noncontinuously (Zhang et al., 2017). In the present study, we aimed to develop a flow-through electrochemical sanitizing unit that can produce NEW continuously through further development of the previous unit. NEW produced through two different methods using this portable flow-through electrolytic sanitizing unit were analyzed, and their sanitizing effects were tested. Two kinds of widely used electrodes (RuO$_2$-IrO$_2$-TiO$_2$ [Ru/Ir] and IrO$_2$-Ta$_2$O$_5$/TiO$_2$ [Ir/Ta]) were investigated to produce NEW, electron spin resonance (ESR) was used to check the free radicals in the NEW. Based on these results, a pathway to produce NEW using the flow-through electrolytic cell was provided.

Materials and Methods

Portable flow-through NEW producing unit

Figure 1(A) shows an overview of the developed portable flow-through NEW producing unit, which consists of electrolyte containers, a peristaltic pump, a controller (Nanjing Runzefluid Control Equipment CO., Ltd, Nanjing, Jiangsu, China), two serially connected electrolytic cells (Dongguan Sunrise Environmental Technology Co., Ltd, Guangzhou, Guangdong, China; L × W × H, 100 mm × 50 mm × 10 mm), and 2 direct current (DC) power supplies (KXN-305D, Shenzhen Zhaoxin Electronic Instrument Equipment Co., Ltd, Shenzhen, Guangdong, China). Figure 1(B) and 1(C) show schematic illustrations of the portable flow-through NEW producing unit configured in 2 different ways: redirecting the cathode yield of 1st electrolytic cell back to the anode chamber of the 2nd electrolytic cell of the unit (B); and redirecting the anode yield of the 1st electrolytic cell back to the cathode chamber of the 2nd electrolytic cell of the unit (C). NEW was generated from the 2nd electrolytic cell for both the 2 methods.

Analytical measurements of NEW

All chemicals used in this study were of analytical grade. Deionized water (DI) was used for cleaning and to dissolve solutes. The free available chlorine (FAC) concentration was determined using the iodometric method (Hao et al., 2012; Hsu, 2005). Briefly, potassium iodide was mixed with a sample of EW. Chlorine was reduced by potassium iodide, resulting in the formation of iodine, which was titrated with sodium thiosulfate (Na$_2$S$_2$O$_3$). The oxidation-reduction potential (ORP) was measured using a Mettler Toledo Seven compact ORP meter (Metrohm Singapore Pte, Ltd, Singapore), and pH was measured using a Thermo Orion 410 pH meter (Thermo Scientific, Waltham, MA, U.S.A.).

Electrochemical characterization of RuO$_2$-IrO$_2$/TiO$_2$ and IrO$_2$-Ta$_2$O$_5$/TiO$_2$ electrodes

Linear sweep voltammetry (LSV) curves of the RuO$_2$-IrO$_2$/TiO$_2$ (Ru/Ir) and IrO$_2$-Ta$_2$O$_5$/TiO$_2$ (Ir/Ta) anodes were carried out using an Autolab type III potentiostat/galvanostat. A platinum plate was used as the counter electrode, and an Ag/AgCl electrode as the reference. The fast linear scanning method was employed over a potential range of 0 to 1.5 V, at a scanning speed of 20 mV/s. The test sample was covered with epoxy resin except for a round exposed area of 1 cm$^2$. LSV measurements were performed in saturated NaCl solution and 0.5 M H$_2$SO$_4$ for different purposes (Ren et al., 2015; Tang, Li, Li, Chen, & Zeng, 2016).

Efficacy of the sanitizing effect

The sanitizing effects of NEW samples (20 mL) generated from the developed portable electrolytic unit were compared with those of NEW samples generated from a commercial electrolytic unit (Hoshizaki ROX-10WB3-EW, Smitech (Asia) Pte Ltd, Singapore). Escherichia coli O157:H7 (strain C7927), and Listeria monocytogenes (strain ATCC BAA-839) were used in this study. The bacterial activity of the NEW samples was determined as previously reported, with slight modifications (Yang et al., 2013). Briefly, 24-hr bacterial suspensions (10 mL each in TSB) were centrifuged (3000 × g, 4 °C) for 10 min, and the resulting pellets were rinsed with 10 mL of sterile 0.1% peptone water (PW), centrifuged, and resuspended in 10 mL of PW. Subsequently, 1 mL of each bacterial suspension was mixed with 9 mL of each NEW sample for 30 s. Aliquots (1 mL) were added to 9 mL of neutralizing buffer solution (5.2 g/L; Becton, Dickinson and Comp., Sparks, Md., U.S.A.). The neutralized mixture was serially diluted for plating on petri dishes with Tryptic Soya Agar (TSA) as media. Following incubation at 37 °C for 24 hr, bacterial colonies were counted. For each bacterial strain, two separate experiments were performed independently. For each experiment, independent parallel groups were carried out in duplicate, resulting in 4 observations for each strain.

Identification of free radical species by ESR

The free radicals were examined according to the methods detailed in previous studies, with slight modifications (Mokudai, Nakamura, Kanno, & Niwano, 2012; Stan, Woods, & Daeschel, 2005). Aliquots (180 μL) of NEW/EW produced by the portable electrolytic sanitizing unit and CNEW (commercial neutral EW; produced by mixing the anode and cathode products) were mixed with 40 μL of 1 M 5,5-dimethyl-1-pyrroline-N-oxide (DMPO) for 10 s. Immediately after mixing, the mixture was transferred to an ESR spectrometry cell, and the ESR measurements were started after 30 s on an X-band ESR spectrometer. In this study, ethanol (50%) was used as an OH radical scavenger, mixed with aliquot (180 μL) of NEW and 40 μL of 1M DMPO. The measurement conditions were as follows: field modulation frequency, 100 kHz; field modulation width, 0.1 mT; amplitude, 2; sweep time, 30 s; time constant, 0.03 s; microwave frequency, 9.192 GHz; microwave power, 1 mW.

Statistical analysis

Data were reported as the mean ± standard deviation. Analysis of variance (ANOVA) and Duncan’s test were performed using SAS software (SAS Inst. Inc., Cary, N.C., U.S.A.). Statistical significance was set at P < 0.05.

Results and Discussion

Development of the electrolytic sanitizing unit

Producing NEW by redirecting the cathode product. Dimensionally stable anodes (DSA), especially low-cost Ru/Ir electrodes, are widely used to produce EW because of their lower corrosion rates and higher selectivity and efficiency in the electrochemical oxidation of Cl ions to Cl$_2$ (Le Luu, Kim, & Yoon, 2015; Tang et al., 2016). Recently, the study of the chlorine evolution reaction of Ir/Ta electrodes has demonstrated high electrode catalytic activity and chlorine production (Ren et al., 2015). In this section, the electrolytic cell equipped with Ir/Ta electrodes was investigated.
LSV analysis was first performed to investigate the electrocatalytic activity of these two kinds of electrode. Similarly, the EW produced by a single electrolytic cell (Zhang et al., 2017) with these two different electrode materials was checked. Figure 2 shows the representative LSV curves (Figure 2A, 2B) and half-wave potentials (Figure 2C, 2D) of Ru/Ir and Ir/Ta electrodes in an acidic electrolyte (0.2 M H₂SO₄) and in saturated NaCl solution. In H₂SO₄, the half-wave potential of Ru/Ir was significantly larger than that of Ir/Ta (Figure 2C). Accordingly, in Figure 2A, above the threshold potentials for the oxygen evolution, at constant current densities, the electrode potential of Ir/Ta was greater than that of Ru/Ir. This finding clearly demonstrated higher...
Electrocatalytic activity toward the reaction of oxygen evolution (OER) for the Ir/Ta electrode, which was in consistent with previous studies (Comninellis et al., 2008). However, the differences in the electrocatalytic activity toward the reaction of chlorine evolution were not significant, according to the LSV and half-wave potential in the NaCl solution (Figure 2B and 2D).

Figure 3 shows FAC, ORP, and pH trends produced by a single electrolytic cell with two different electrode materials at flow rates of 900, 800, 700, 600, 500, and 400 mL/min, with NaCl concentrations of 10 and 2 g/L. There was no significant difference in the FAC, ORP, and pH between the two electrolytic cells with different electrodes at a high NaCl concentration. However, at a low NaCl concentration, the ORP was significantly lower for the electrolytic cell with an Ir/Ta electrode compared with that for the Ru/Ir electrode. These results were in agreement with the electrochemical property results, indicating a higher electrode stability of Ir/Ta electrode under oxygen evolving conditions, such as using an alkaline solution as the electrolyte (Comninellis et al., 2008). Thus, in the following experiments, we only used a Ru/Ir electrode in the second electrolytic cell.

Based on these results, 2 and 10 g/L NaCl solutions were tested to produce NEW by connecting the 2 portable electrolytic cells with different electrodes serially at different flow rates. FAC, pH and ORP of the NEW produced were investigated, as shown in Figure 4A–C. For the Ru/Ir–Ru/Ir unit (electrolytic cell equipped with a Ru/Ir electrode connected with another Ru/Ir electrode), all groups achieved near neutral pH, from 6.46 to 7.17 (Figure 4B) except at the flow rate of 400 mL/min and an NaCl concentration of 2 g/L. However, for the Ru/Ir–Ir/Ta unit (an electrolytic cell equipped with a Ru/Ir electrode connected to an Ir/Ta electrode), except for the groups at high flow rate (500 to 900 mL/min) and at a high NaCl concentration (10 g/L), the other NEWs all had an acidic pH. This was probably because of the stronger OER activity of Ir/Ta than the Ru/Ir electrode.

For the Ru/Ir–Ru/Ir unit, the FAC ranged from 3.7 to 82.0 mg/L, with the volume from 52 to 122 mL/min. For the Ru/Ir–Ir/Ta unit, with 2 g/L NaCl solution, the FAC concentration was lower than 1.5 mg/L under all flow rates. Accordingly, under these conditions, the ORP of NEW produced was also very low, ranging from 147.2 to 238.5 mV (range from 813.4 to 974.6 mV for NEW produced from Ru/Ir–Ru/Ir unit). It is probable that such conditions induced the selectivity for oxygen formation reducing the production of chlorine (Karlsson, & Cornell, 2016).

In general, compared with the portable flow-through electrolytic NEW generator equipped with the Ru/Ir electrode, the one with the Ir/Ta electrode did not enhance the FAC production or ORP value of NEW. Thus, in later part of this study, we only investigated the developed electrolytic unit with a Ru/Ir electrode.

Producing NEW by redirecting anode products. We next assessed NEW production by redirecting the anode yields back to the cathode chamber during electrolysis. Figure 5 shows the trend of FAC (A, C), ORP, and pH (B, D) during electrolysis using the developed unit at different NaCl concentrations: A and B, 10 g/L; C and D, 2 g/L. For the 10 g/L NaCl solution, the current density of the 1st electrolytic cell was kept stable at 30 mA/cm$^2$, and the 2nd electrolytic cell changed from 7.5 to 20.625 mA/cm$^2$ to maximize FAC production in NEW during electrolysis. Similarly, for the 2 g/L NaCl solution, the current density of the 2nd electrolytic cell was kept stable at 30 mA/cm$^2$, while that of the first cell changed from 22.5 to 30 mA/cm$^2$. For both concentrations of NaCl, at different current densities, there
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Figure 3—Comparison of the free available chlorine (FAC) concentration (A), oxidation-reduction potential (ORP) (B), and pH (C) produced by a single electrolytic cell with 2 different electrode materials at different flow rates in different NaCl concentrations: 10 g/L (H) and 2 g/L (L). * Means within each flow rate with different lowercase letters are significantly different among the different kind of electrolytic cells (P < 0.05); means within each group with different capital letters are significantly different among different flow rates (P < 0.05).

was no significant change in FAC, while the pH could be adjusted to neutral. The ORP was inversely proportional to the pH (Figure 5), such that decreasing the pH increased the ORP. Taking into account of the results of redirecting the cathode product, a hypothetical proposed portable NEW (NEW1) sanitizing unit for domestic and small-scale industry especially organic food industry use is shown in Figure 6.

Considerably lower FAC and ORP values were observed in this experiment compared with those in section Producing NEW by redirecting the cathode product. Even at the higher NaCl concentration (10 g/L) and low flow rate (400 mL/min), the FAC concentration was no larger than 25 mg/L and ORP was lower than 200 mV. This indicated not only pH neutralization happened in the cathode chamber of 2nd electrolytic cell, but also the reaction which can reduce ORP and FAC also happened. It is probable that, in addition to OH\(^{-}\) and H\(_2\), some other elements with antioxidant properties were produced in the cathode part, which reacted with the oxidants produced from the anode chamber of the first electrolytic cell. This was in line with a previous study in which an unstable transient H\(_2\) element was involved in alkaline water production (Henry, & Chambron, 2013). It may cause a low sanitizing effect compared with the NEW produced by redirecting the cathode yields back to the anode chamber, which will be discussed more in the next section.
Efficacy of sanitizing effect

Two kinds of NEW with the same FAC but produced via different principles (NEW1, NEW2, produced by redirecting the cathode product and anode products, respectively) were evaluated. To make the comparison, NEW produced by mixing the anode and cathode products of commercial EW generator (CNEW) was also involved.

The properties of different NEWs used to inactivate *E. coli* O157:H7 and *L. monocytogenes* in this study are shown in Table 1. The pH values of the NEWs produced from different generators and principles ranged from 5.78 to 6.77. The ORP values ranged from 103.0 to 876.6 mV.

Table 1 shows the surviving populations of *E. coli* O157:H7 C7927 and *L. monocytogenes* BAA–839 after treatment with the NEW solutions. There was no significant difference between the sanitizing effects on different strains treated with the same NEW, while the sanitizing effect increased with the increasing FAC concentration in the different NEW. At a FAC concentration of 40 mg/L, the populations of *E. coli* O157:H7 and *L. monocytogenes* in the treated samples decreased to undetectable levels (as determined by both plating and enrichment procedures) after 30 s of exposure to NEW. For a FAC concentration of 4 mg/L, the antimicrobial effect of different NEW products was in the order of NEW1 > CNEW > NEW2. NEW1 inactivated *E. coli*
O157:H7 by around 2.75 log CFU/mL reductions, which was significantly higher than 0.72 and 1.89 log reductions achieved by NEW2 and CNEW, respectively. Similar results were observed for L. monocytogenes.

The EW’s sanitizing effects depend on the FAC (include hypochlorous acid [HClO], hypochlorite ion [ClO] and chlorine gas [Cl\textsubscript{2}]), ORP, and pH. The pH values of NEWs (around 4 mg/L) produced from different generators and principles ranged from 5.78 to 6.45 in our study. At this pH range, HClO is the chlorine species with the highest proportion in solution (Len et al., 2000). NEW1, NEW2, and CNEW all contained similar amount of FAC (4 mg/L); therefore, this sanitizing result can probably be explained by the ORP order: NEW1 > CNEW > NEW2 (Table 1). The ORP of a solution is an indicator of its oxidizing or reducing strength, with higher positive ORP values indicating a greater oxidizing strength. Previous reports (Liao, Chen, & Xiao, 2007) suggested that the ORP of EW might be the primary factor affecting microbial inactivation, which

Figure 5—Effect of current density\(^*\) on the free available chlorine (FAC) concentration (A, B) oxidation-reduction potential (ORP) (C, D), and pH (E, F) during the neutral electrolyzed water (NEW) electrolysis process using the portable flow-through NEW producing unit with a flow rate of 400 mL/min at different NaCl concentrations: 2 g/L (A, C, E), 10 g/L (B, D, F)\(^{**}\)

\(^*\)At an NaCl concentration of 10 g/L, to attain the highest FAC concentration in the produced NEW, the current density of the 2nd electrolytic cell was maintained at a stable 30 mA/cm\(^2\), and the current density of 1st cell was changed from 22.5 to 30 mA/cm\(^2\);

At a NaCl concentration of 2 g/L, to attain the highest FAC in the produced NEW, the current density of the 1st electrolytic cell was kept stable at 30 mA/cm\(^2\), and the current density of the 2nd cell was changed from 7.5 to 20.625 mA/cm\(^2\).

\(^{**}\)Means within each current density with different lowercase letters are significantly different (\(P < 0.05\)).
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Figure 7—Electron spin resonance (ESR) spectra of neutral electrolyzed water (NEW) produced by the portable flow-through NEW producing unit. (A) DI, (B) NEW1 (produced by redirecting cathode yields back to the anode chamber), (C) NEW1 + 2.5% ETOH (ethanol), (D) NEW2 (produced by redirecting anode yields back to the cathode chamber), (E) Electrolyzed water (EW, produced by the developed single electrolysis unit without redirecting), (F) CNEW (commercial neutral electrolyzed water; produced by mixing the commercial unit’s anode and cathode product after electrolysis).

Table 2—Different views on the production of OH in electrolyzed water (EW)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Type of electrolytic cell</th>
<th>Type of EW</th>
<th>Note</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of OH-</td>
<td>Batch-type generator, Nonmembrane</td>
<td>AEW 1%, 0.6 A, 15 min electrolysis</td>
<td></td>
<td>(Mokudai et al., 2012)</td>
</tr>
<tr>
<td></td>
<td>Nonmembrane</td>
<td>NEW, AEW N.V. 10 min electrolysis</td>
<td></td>
<td>(Xiong et al., 2010)</td>
</tr>
<tr>
<td></td>
<td>With membrane</td>
<td>AEW 0.1%, 10 min electrolysis</td>
<td></td>
<td>(Suzuki et al., 2002)</td>
</tr>
<tr>
<td></td>
<td>Continuous generator</td>
<td>With membrane 1% 0.8 A, 400 mL/min electrolysis</td>
<td></td>
<td>This study</td>
</tr>
<tr>
<td>Nonpresence of OH-</td>
<td>Batch-type generator</td>
<td>With membrane AEW 0.05%; 10 min electrolysis</td>
<td></td>
<td>(Stan et al., 2005)</td>
</tr>
<tr>
<td></td>
<td>With membrane</td>
<td>AEW 0.05%; 10 min electrolysis</td>
<td></td>
<td>(Stan &amp; Daeschel, 2005)</td>
</tr>
<tr>
<td></td>
<td>Continuous generator</td>
<td>With membrane AEW 13.6%, 14.4 ± 0.4 A electrolysis</td>
<td></td>
<td>(Stan, &amp; Daeschel, 2005)</td>
</tr>
<tr>
<td></td>
<td>With membrane</td>
<td>AEW 13.6%, 14.4 ± 0.4 A electrolysis</td>
<td></td>
<td>(Stan et al., 2005)</td>
</tr>
</tbody>
</table>

AEW, acidic electrolyzed water; N.V., not available.
The most accepted mechanism of NEW production would be the direct electro-catalysis of \( \text{Cl}^{1-} \) to \( \text{Cl}_2 \), such as the Volmer–Krstalik–Tafel mechanism (Le Lunn et al., 2015; Trasatti, 1987). However, the indirect oxidation of \( \text{Cl}^{1-} \) mediated by \(-\text{OH}\) and some other radical reactions were also investigated recently for the strong antimicrobial effect of these free radicals (Hao et al., 2012; Mokdadi et al., 2012; Saran et al., 1999; Xiong et al., 2010). We proposed a pathway for chlorine production from both perspectives. Our portable, flow-through electrolytic sanitizing unit improved the presence of \(-\text{OH} \) and \( \text{O}_2^{-} \) in NEW. In particular, the existence of hydroxide ions can amplify the production of these free radicals, which is different from a common chlorine sanitization (Mohamed, Parveen, & Oscar, 2015).

**Conclusions**

A portable flow-through electrolytic sanitizing unit was developed to produce NEW. It provided NEW with a FAC ranging from 3.7 to 82.0 mg/L, near neutral pH between 6.46 and 7.17, and an ORP between 805.5 and 895.8 mV. The produced NEW (formed by redirecting of the catholyte solution back to the anode chamber) had strong bactericidal activity: a FAC concentration of 40 mg/L achieved >6 log CFU/mL reductions, and a FAC concentration of 4 mg/L achieved >2 log CFU/mL reductions. Moreover, the NEW produced by this method had stronger bactericidal effects on both *E. coli* O157:H7 and *L. monocytogenes* compared with NEW produced by a CNEW. In addition, \( \text{OH} \) (a strong antimicrobial agent) was present in NEW produced by redirecting the cathode product in the portable flow-through electrochemical sanitizing unit. The results suggest that the developed portable flow-through electrolytic unit promises to produce NEW that could control foodborne pathogens.

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