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Development of a portable electrolytic sanitising unit for the production of neutral electrolysed water

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ABSTRACT

The aim of this study was to develop and evaluate the characteristics and performance of a portable electrolytic sanitising unit. Free available chlorine (FAC), oxidation-reduction potential, and pH of electrolysed water were measured. Response surface methodology coupled with a Box-Behnken design was used to describe the input-output relationship and optimise FAC production. A partial catholyte solution was reintroduced to electrolysis for generating neutral electrolysed water. The result found that RuO_2-IrO_2/TiO_2 electrode was very effective. A FAC concentration of 4 mg/L achieved >2 log CFU/mL reduction, while a FAC concentration of 40 mg/L achieved >6 log CFU/mL reduction in *Escherichia coli* O157:H7 and *Listeria monocytogenes* BAA-839. The developed sanitiser had a pH of 7.08 ± 0.08, and the commercial sanitiser had a pH of 3.77 ± 0.18. The developed sanitiser had similar bactericidal effects as the commercial sanitiser. The results revealed that the developed sanitising unit is promising for the control of foodborne pathogens.

1. Introduction

Adequate sanitising treatments should be applied during the processing and preparation of fruits and vegetables in family kitchens and food industries. Current household sanitisers are not favored by consumers because of the presence of harmful chemicals. Recently, the consumption of organic foods has increased worldwide, especially in developed countries (Li et al., 2015; Liu, Tan, Yang, & Wang, 2017; Yu & Yang, 2017). U.S. regulations have established that ozone and few other sanitising agents are allowed to clean organic foods and equipment used in organic food processing. However, these chemical sanitisers have limited availability and sanitising effects (Zhang & Yang, 2017; Ölmez & Kretzschmar, 2009). Therefore, it is important to develop sanitisers that are suitable for family kitchens and food industries. With increasing consumption of organic foods and increased awareness of food safety, the market for this sanitiser will be significant.

EW, also referred to as acidic EW or hypochlorous acid, is produced by electrolysing a diluted NaCl solution with direct current (DC) in an electrolytic cell containing a cation ion-exchange membrane that separates the anode side and the cathode side (Hsu, 2003, 2005; Liao, Chen, & Xiao, 2007). Compared to chlorine (clorox), EW has competitive advantages including being environmentally-friendly because it only uses water and salt as resources. It doesn't involve production, handling and transportation of using conventional chlorine (Hricova, Stephan, & Zweifel, 2008), economical because the EW production only involves water, salt and electricity. It can be generated on site when needed, being much less costly than conventional chlorine aspect of sanitiser generation, transporting and handling (Hricova et al., 2008; Huang, Hung, Hsu, Huang, & Hwang, 2008), safety thus it has been approved as a food additive in Japan, and the application on food was also approved by both U.S. Food and Drug Administration (FDA) and U.S. Department of Agriculture (USDA) (Hricova et al., 2008), and having strong sanitising effect because of major component being hypochlorous acid and there are some other effective components including free radicals, active oxygen, hydrogen peroxide and ozone gas, which are not existed in clorox and with higher oxidation-

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reduction potential (ORP) (Yang, Feirtag, & Diez-Gonzalez, 2013). However, at low pH, EW is corrosive, has a short shelf-life, and may be toxic to the operator (Ayebah & Hung, 2005; Waters, Tatum, & Hung, 2014; Xuan et al., 2016). A feasible solution is the use of a nearly neutral EW (NEW; pH ~6).

Even though several studies have reported the bactericidal effects of both EW and NEW (Luo, Kim, Wang, & Oh, 2016; Park, Guo, Rahman, Ahn, & Oh, 2009; Thorn, Lee, Robinson, Greenman, & Reynolds, 2012; Waters & Hung, 2014; Zhang, Li, Jadeja, Fang, & Hung, 2016), few researchers have investigated the effects of processing factors on the performance of EW/NEW generators. Current commercial EW-producing units are quite large and not convenient for applications in households and small food industries (Yang et al., 2013). A portable, user-friendly NEW generator is necessary to meet the market demands and improve food safety.

The aim of this study was to develop and evaluate the characteristics and performance of a portable and affordable electrolytic sanitising unit. We evaluated the effects of NaCl solution flow rate, NaCl concentration, and current density on pH, ORP, and free available chlorine (FAC) using a mathematical model. We investigated the optimum conditions of FAC production from this small-scale unit. Under optimised conditions, a reflux experiment was performed with different reflux ratios of catholyte to produce NEW. Finally, we studied the sanitising effects of EW and NEW generated from this system.

2. Materials and methods

2.1. Development of a small-scale electrolytic unit

A small-scale electrolytic unit was developed (Fig. 1A and B). It consisted of an electrolyte container, a peristaltic pump, a controller (Nanjing Runze Fluid Control Equipment Co., Ltd, Nanjing, China), an electrolytic cell (10 cm × 5 cm × 1 cm, length × width × height; Dongguan Sunrise Environmental Technology Co., Ltd, Guangdong, China), and a DC power supply (KXN-305D, Shenzhen Zhaoxin Electronic Instrument Equipment Co., Ltd, Shenzhen, China). The anode and cathode consisted of RuO_2-IrO_2/TiO_2 electrodes separated by a polytetrafluoroethylene membrane, which allowed for the separate production of EW and catholyte. The geometric area of the electrode was 27 cm^2.

2.2. Analytical measurements of EW

All chemicals used in this study were of analytical grade. Deionised water (DI) was used for cleaning and dissolving solutes. FAC concentration was determined by the iodometric method (Hsu, 2005; Qin, Li, Chen, & Russell, 2002). Briefly, potassium iodide was mixed with a sample of EW. Chlorine was reduced by potassium iodide, resulting in the formation of an equivalent amount of iodine, which was titrated with sodium thiosulfate ($Na_2S_2O_3$). The concentration of FAC was calculated using following equation:

$$FAC = \frac{(V_2 - V_1)^* C_{Na_2S_2O_3}{}^* M}{V_E}$$

where $C_{Na_2S_2O_3}$ represents the concentration of the $Na_2S_2O_3$ titrating solution (mol/L), V_2 represents the volume of the $Na_2S_2O_3$ titrating solution consumed in the treated sample (mL), V_1 represents volume of the $Na_2S_2O_3$ titrating solution consumed in the blank sample (mL), V_E represents the volume of EW/NEW (mL), M represents the molar mass of chlorine (35,453 mg/mol).

ORP was measured with a Mettler Toledo Seven compact ORP meter (Metrohm Singapore Pte, Ltd, Singapore), and pH was measured with a Thermo Orion 410 pH meter (Thermo Scientific, Waltham, MA, USA). The yield was obtained based on average volume/min of generated EW solution in 20 min.

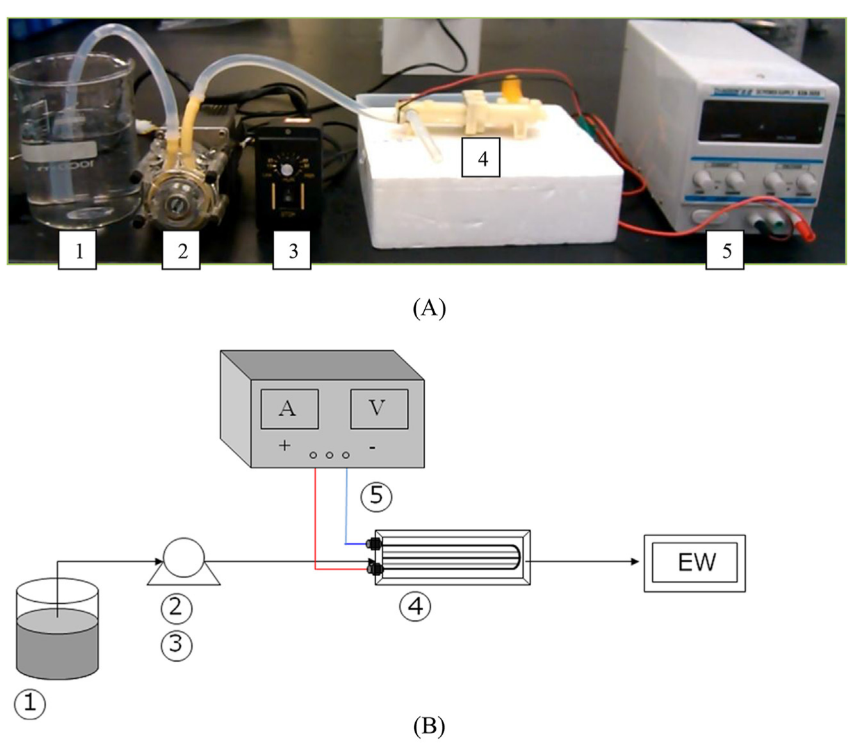

Fig. 1. (A) Overview of the developed small-scale electrolytic unit. (B) Schematic representation of the small-scale electrolytic unit. 1, electrolyte; 2, pump; 3, controller; 4, electrolytic cell; 5, power supply.