JOURNAL OF FOOD AND DRUG ANALYSIS 23 (2015) 729–734

Available online at www.sciencedirect.com

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journal homepage: www.jfda-online.com

Original Article

Effects of electrode settings on chlorine generation efficiency of electrolyzing seawater

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ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form
29 April 2015
Accepted 18 June 2015
Available online 5 August 2015

Keywords:
chlorine
current density
current efficiency
electrolyzed seawater
storage

ABSTRACT

Electrolyzed water has significant disinfection effects, can comply with food safety regulations, and is environmental friendly. We investigated the effects of immersion depth of electrodes, stirring, electrode size, and electrode gap on the properties and chlorine generation efficiency of electrolyzing seawater and its storage stability. Results indicated that temperature and oxidation-reduction potential (ORP) of the seawater increased gradually, whereas electrical conductivity decreased steadily in electrolysis. During the electrolysis process, pH values and electric currents also decreased slightly within small ranges. Additional stirring or immersing the electrodes deep under the seawater significantly increased current density without affecting its electric efficiency and current efficiency. Decreasing electrode size or increasing electrode gap decreased chlorine production and electric current of the process without affecting its electric efficiency and current efficiency. Less than 35% of chlorine in the electrolyzed seawater was lost in a 3-week storage period. The decrement trend leveled off after the 1st week of storage. The electrolyzing system is a convenient and economical method for producing high-chlorine seawater, which will have high potential applications in agriculture, aquaculture, or food processing.

1. Introduction

Electrolyzed oxidizing (EO) water is an antimicrobial agent which possesses strong antimicrobial activity against most pathogenic bacteria that are important to food safety and has applications in many food industries, such as fresh vegetables, fruits, eggs, poultry, and seafood. EO water is commonly produced by passing a diluted salt solution through an electrolytic cell, within which the anode and cathode are separated by a membrane. By subjecting the electrodes to direct current voltages, negatively charged ions such as chloride and hydroxide in the diluted salt solution move to the anode to give up electrons and become oxygen gas, chlorine gas, hypochlorite ion, hypochlorous acid, and hydrochloric acid, whereas positively charged ions such as hydrogen and sodium move to the cathode to take up electrons and become hydrogen gas and sodium hydroxide [1]. Two types of water

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http://dx.doi.org/10.1016/j.jfda.2015.06.007

are produced simultaneously. EO water, with low pH (2.3–2.7), high oxidation-reduction potential (ORP, > 1000 mV), high dissolved oxygen, and contains free chlorine, is produced from the anode side. By contrast, electrolyzed reducing (ER) water, with high pH (10.0–11.5), high dissolved hydrogen, and low ORP (−800 mV to −900 mV), is produced from the cathode side. ER water with strong reducing potential can be used to remove dirt and grease from items such as cutting boards and other kitchen utensils [1]. Electrolyzed water is environmentally friendly, has significant disinfection effects, and can comply with food safety regulations [2].

Electrolyzed seawater, similar to EO water, has strong disinfection effects against most pathogenic organisms and is also an effective antimicrobial agent. However, it is not as acidic as EO water and not as alkalic as ER water because it is commonly produced using nondiaphragm electrolyzing systems. EO water and ER water are generated at the anode and cathode, respectively, but are mixed in the electrolyzer, which yields a product solution of mild pH and is more user- and facility-friendly. It has been used in many antifouling systems [3,4], aquaculture, and seafood processing. For example, Kasai et al [5,6] studied disinfectant effects of electrolyzed seawater on viable bacteria in hatchery seawater using batch and continuous electrolysis systems. They reported a 2–4-log reduction of viable bacteria after treatment with electrolyzed seawater containing 0.5–1.0 mg/L chlorine for 1 minute. Watanabe and Yoshimizu [7] disinfected various utensils and equipment for aquaculture and reported a >3-log reduction of viable bacteria after treatment with electrolyzed seawater containing 0.5–1.5 mg/L chlorine for 30–120 minutes. Kasai and Yoshimizu [8] studied disinfection of seawater from a fishing port using an electrolysis apparatus and found many useful applications in sanitation of fish holding tanks, port deck, and fishing equipment. Kimura et al [9] reared sea urchins for 2 days using electrolyzed seawater containing 0.76 mg/L chlorine and found that 90% of bacteria in sea-urchin's viscera were eliminated. Kasai et al [10] used electrolyzed seawater which contained 0.2 mg/L chlorine to depurate contaminated oysters and found that *Escherichia coli* in the oysters was reduced to below detection limits. Although many applications have been reported in antifouling systems, aquaculture, and seafood processing, few papers have reported on chlorine producing efficiency, quality, and storage stability of electrolyzed seawater.

Because most of the surface area of the Earth is covered by seawater, it will be very useful to make sustainable applications of this resource. Therefore, it is interesting to study electrolyzed seawater because of its high potential in applications in agriculture, aquaculture, and food processing. As a preliminary study in developing optimal electrolyzed seawater and its manufacturing system, seawater is electrolyzed and its chlorine generation efficiency, product quality, and storage stability are investigated in this study.

2. Materials and methods

2.1. Seawater samples

Seawater samples (provided by the Taiwan Yes Deep Ocean Water Co., Ltd., Hualien County, Taiwan) were drawn at 50 m below sea surface at approximately 1.5 km off the coastline of the Hualien County in Eastern Taiwan. The seawater was kept in 30-L blue/gray high density polyethylene tanks and shipped to the laboratory by car immediately after sampling. Fundamental properties and major compositions of the seawater samples are shown in Table 1.

2.2. Electrolysis process and storage conditions

Ten liters of each seawater sample was electrolyzed for 2 hours in a 12.9-L (16 cm diameter × 64 cm high) cylindrical polypropylene electrolyzing cell equipped with a pair of 50-mm long platinum-plated titanium mesh anodes and cathodes to simulate a popular batch practice of electrolyzing seawater in plastic buckets, which is adopted by some aquaculturists and seafood processors. The anode and cathode (Model SUR-303; Surchem C&S Internation Corp., Taipei City, Taiwan), which were titanium mesh electrodes plated with 3.75 μm of platinum, were powered by a rectifier (Model MC48-4D; Surchem C&S Internation Corp.), which controlled the cell potential and/or electric current of the electrolysis system. A constant-potential mode of operation was adopted in this study. The cell potential was set at 8.0 V. The other operation conditions are detailed in Table 2. Effects of electrode size, electrode gap, electrode immersion depth beneath the seawater surface, and additional stirring were investigated. Stirring was done using a 16-mm × 40-mm (diameter × length) Teflon spindle-shape magnetic stir bar powered by a stirrer (Model PC-101; Corning Inc., Acton, MA, USA) at speed setting 2.0, which was approximately 400 rpm. Electrolysis parameters and seawater properties were monitored during the process.

One liter each of the electrolyzed seawaters produced as mentioned above was kept in a sealed brown glass bottle at room temperature (26–32°C) for up to 3 weeks to investigate its storage stability. Seawater properties were measured at the end of each week.

2.3. Analytical measurements

The ORP and pH values of the electrolyzing seawaters were measured using pH/mV/ISE meters (model Sension 4; Hach Co., Loveland, Colorado, USA) equipped with an ORP and a pH electrode (part 5779601-003B and 5773597-003B, respectively, Van London Co., Houston, TX, USA). Electrical conductivity (EC) was measured using a conductivity meter (model Sension

Table 1 – Basic properties and major compositions of seawater samples.

Property	Temperature (°C)	22.5 ~ 23.8
	pH	8.10 ~ 8.20
	Salinity (psu)	34.2 ~ 34.5
Element (mg/L)	Chloride	19,060 ~ 19,860
	Sodium	11,320 ~ 11,500
	Magnesium	1327 ~ 1330
	Calcium	400 ~ 441
	Potassium	400 ~ 414

Data provided by the Stone & Resource Industry R&D Center (Hualien County, Taiwan).