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Original Article

Effects of process conditions on chlorine generation and storage stability of electrolyzed deep ocean water

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ABSTRACT

Electrolyzed water is a sustainable disinfectant, which can comply with food safety regulations and is environmentally friendly. We investigated the effects of platinum plating of electrode, electrode size, cell potential, and additional stirring on electrolysis properties of deep ocean water (DOW) and DOW concentration products. We also studied the relationships between quality properties of electrolyzed DOW and their storage stability. Results indicated that concentrating DOW to 1.7 times increased chlorine level in the electrolyzed DOW without affecting electric and current efficiencies of the electrolysis process. Increasing magnesium and potassium levels in DOW decreased chlorine level in the electrolyzed DOW as well as electric and current efficiencies of the electrolysis process. Additional stirring could not increase electrolysis efficiency of small electrolyzer. Large electrode, high electric potential and/or small electrolyzing cell increased chlorine production rate but decreased electric and current efficiencies. High electrolysis intensity decreased storage stability of the electrolyzed seawater and the effects of electrolysis on DOW gradually subsided in storage. DOW has similar electrolysis properties to surface seawater, but its purity and stability are better. Therefore, electrolyzed DOW should have better potential for applications on postharvest cleaning and disinfection of ready-to-eat fresh produce.

1. Introduction

Electrolyzed water is environmental friendly, has significant disinfection effects, and can comply with food safety regulations [1]. Because most surface area of the Earth is covered by seawater, it would be very useful to make sustainable applications of this resource. Electrolyzed seawater, because of its significant disinfection effects, has been used in many antifouling systems [2,3], aquaculture, and seafood processing. For example, Kasai et al [4,5] studied disinfectant effects of electrolyzed seawater on viable bacteria in hatchery seawater

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using a batch and a continuous electrolytic systems. They reported a 2–4 log reduction of viable bacteria after treated with electrolyzed seawater containing 0.5–1.0 mg/L chlorine for 1 minute. Watanabe et al [6] 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 [7] studied disinfection of seawater from fishing port using an electrolytic apparatus and found useful applications for sanitation of the fish holding tank, port deck, and fishing equipment. Kimura et al [8] reared sea urchins for 2 days using electrolyzed seawater containing 0.76 mg/L chlorine and found that 90% of bacteria in the sea-urchins' viscera were eliminated. Kasai et al [9] used electrolyzed seawater that contained 0.2 mg/L chlorine to depurate contaminated oysters and found that *Escherichia coli* in the oysters was reduced to below detection limits [9].

Although many applications of electrolyzed seawater had been reported in aquaculture and seafood processing, few applications have been reported in the agriculture or food processing industries, probably because of sanitary concerns. Plankton and bacteria are abundant in seawater and certain coastal seawaters have been polluted [10,11]. However, deep ocean water (DOW) is the cold, salty seawater found deep below the surface of Earth's oceans, which makes up about 90% of the ocean volume. DOW has low temperature, typically from 0°C to 3°C, and a salinity of about 35 psu [12]. Although surface seawater could be contaminated by pollution or civilization, DOW has no such concern, because it has remained unpolluted because of high pressures and low temperatures for the past 1,000 years.

To develop electrolyzed seawater for food and agriculture applications, especially for postharvest cleaning and disinfection of ready-to-eat fresh produce, DOW and DOW concentration products are electrolyzed and their properties as well as storage stability are investigated in this study.

2. Materials and methods

2.1. Seawater samples

All seawater samples used in this study were provided by the Taiwan Yes Deep Ocean Water Co., Ltd. (Hualien County, Taiwan). DOW was drawn at 662 m below the Pacific Ocean at approximately 5.0 km off the coastline of the Hualien County in eastern Taiwan. Surface seawater was drawn at 50 m below the sea surface at approximately 1.5 km off the coastline of Hualien County. A DOW concentrate, which is a concentrated solution of DOW, a DOW salt, which is a dried product made from DOW, and a product labeled as LC-40K, which is a purified DOW solution high in magnesium and potassium minerals, were processed products of DOW produced via unit operations such as ultrafiltration, reverse osmosis, and vacuum evaporation (Taiwan Yes Deep Ocean Water Co., Ltd., Hualien County, Taiwan). Table 1 shows the compositions of major elements in these seawater samples. Table 2 shows a comparison on composition and property of DOW and surface seawater samples.

Table 2 – A comparison on compositions and properties of surface seawater and deep ocean water samples.

		Surface seawater	Deep ocean water
Composition	Nitrite (μM)	0.08 ~ 0.11	<0.03
	Chlorophyll a (μg/L)	0.12 ~ 0.19	<0.03
Property	Temperature (°C)	22.5 ~ 23.8	9.4 ~ 10.4
	pH	8.10 ~ 8.20	7.70 ~ 7.75
	Salinity (psu)	34.2 ~ 34.5	34.3 ~ 35.0

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

2.2. Electrolysis and storage conditions

This study was divided into three parts. Part 1: 1600 mL of DOW samples and a surface seawater for comparison purpose were electrolyzed for 2 hours in a 2.0 L glass beaker electrolyzing cell equipped with a pair of 50-mm-long anodes and cathodes. The anode and cathode (Model SUR-303, Surchem C&S Internation Corp., Taipei City, Taiwan), which were titanium mesh electrode and/or titanium mesh electrode plated with 3.75 μm of platinum, were powered by a rectifier (Model MC48-4D, Surchem C&S Internation Corp., Taipei City, Taiwan), which controlled the cell potential and/or electric current of the electrolysis system. A constant-potential mode of operation was adopted. The electrodes were immersed in

Table 1 – Compositions of major elements in seawater, deep ocean water and its products.

Element (mg/L or kg)	Surface seawater[a]	DOW[a]	DOW concentrate[b]	LC-40K[b]	DOW salt[b]
Chloride	19,060 ~ 19,860	18840 ~ 19510	28,000~38,000	100,000~150,000	550,000
Sodium	11,320 ~ 11,500	11380 ~ 11430	15,000~20,000	20,000~30,000	377,000
Magnesium	1,327 ~ 1,330	1283 ~ 1320	2,000~3,000	40,000~50,000	4,900
Calcium	400 ~ 441	400 ~ 432	800~1,000	200~500	3,800
Potassium	400 ~ 414	390 ~ 421	500~1,000	7,000~10,000	1,900

LC-40K is a commercialized high magnesium and potassium mineral solution made of DOW; DOW Concentrate is a concentrated solution of DOW; DOW Salt is a dried product made of DOW; LC-40K is a purified DOW solution high in magnesium and potassium minerals. All were provided by the Taiwan Yes Deep Ocean Water Co., Ltd. (Hualien County, Taiwan).
DOW = deep ocean water.
[a] Data provided by the Stone and Resource Industry R&D Center (Hualien County, Taiwan).
[b] Data provided by the Taiwan Yes Deep Ocean Water Co., Ltd. (Hualien County, Taiwan).