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Original Article

Effects of electrolysis time and electric potential on chlorine generation 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. A two-factor central composite design was adopted for studying the effects of electrolysis time and electric potential on the chlorine generation efficiency of electrolyzed deep ocean water (DOW). DOW was electrolyzed in a glass electrolyzing cell equipped with platinum–plated titanium anode and cathode. The results showed that chlorine concentration reached maximal level in the batch process. Prolonged electrolysis reduced chlorine concentration in the electrolyte and was detrimental to electrolysis efficiency, especially under high electric potential conditions. Therefore, the optimal choice of electrolysis time depends on the electrolyzable chloride in DOW and cell potential adopted for electrolysis. The higher the electric potential, the faster the chlorine level reaches its maximum, but the lower the electric efficiency will be.

1. Introduction

Electrolyzed water is an antimicrobial agent that possesses strong bactericidal effects on most pathogenic bacteria that are important to food safety. Electrolyzed water is usually produced by passing a diluted salt solution through an electrolytic cell, within which the anode and cathode are either separated by a membrane or are without a membrane separation. 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. Electrolyzed water is environmentally friendly, has significant disinfection effects, and can comply with food safety regulations [1]. As most of the planet's surface area is covered by seawater, it is reasonable to make sustainable applications of this resource. Electrolyzed seawater, because of its significant disinfection effects, has

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been used in many antifouling systems [2,3], aquaculture, and seafood processing. For example, Kasai et al [4] studied the disinfectant effects of electrolyzed seawater on viable bacteria in hatchery seawater using a batch and a continuous electrolytic system. 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 [4,5]. Watanabe and Yoshimizu [6] disinfected various utencils 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 a fishing port using an electrolytic apparatus and found its useful applications in sanitization of fish-holding tank, port deck, and fishing equipment. Kimura et al [8] reared sea urchin 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 [9] 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 of electrolyzed seawater had been reported in aquaculture and seafood processing, only a few applications were reported in agriculture or food processing industry probably because of sanitary concerns. Plankton and bacteria are abundant in seawater, and certain coastal seawaters had been highly polluted [10,11]. By contrast, deep ocean water (DOW) is the cold, salty seawater found deep below the surface of Earth's oceans. DOW 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]. Whereas surface seawater could be contaminated by pollution or civilization, DOW presents no such concern, because it remains unpolluted in the high-pressure and low-temperature deep ocean for the past thousand years.

In order to develop electrolyzed seawater for food and agriculture applications, especially for postharvest cleaning and disinfection of ready-to-eat fresh produce, surface seawater, DOW, and DOW concentration products were electrolyzed, and their properties as well as storage stability were investigated in our previous studies [13,14]. Results in another previous study showed that the small electrode gap reduced the required cell potential and resulted in high energy efficiency. The optimal choice for electrode gap and cell potential depends on the chlorine level of the electrolyzed DOW to be produced, and a small electrode gap is preferred [15]. As part of a continuing investigation, a two-factor central composite design is adopted for the investigation of optimal electrolysis time and electric potential for electrolyzing DOW in this study.

2. Materials and methods

2.1. Seawater samples

DOW samples used in this study were provided by Taiwan Yes Deep Ocean Water Co., Ltd. (Taipei City, Taiwan, R.O.C.). DOW was drawn at 662 m below the Pacific Ocean at approximately 5 km off the coastline of the Hualien County in eastern Taiwan. Table 1 shows a comparison of major elements, some pollution indicators, and the physical/chemical properties of DOW with those of surface seawater samples collected at a nearby area [16]. Although containing similar major elements, DOW appeared to be colder and purer than the surface seawater, which contained more nitrite as well as chlorophyll and were more alkalinous in its pH values.

2.2. Electrolysis

DOW samples, 1600 mL each, were electrolyzed for designated times (Table 2) in a 2-L glass beaker electrolyzing cell equipped with a pair of 50-mm-long by 25-mm-wide anode and cathode. The anode and cathode (Model SUR-303; Surchem C&S International Corp., Taipei City, Taiwan, R.O.C.), which were titanium mesh electrode plated with 3.75 μm of platinum, were powered by a rectifier (Model MC48-4D; Surchem C&S International Corp.). A constant potential mode of operation was adopted in this study. The electrodes were immersed in seawater at 60 mm beneath the surface. Electrode gap and cell potential were maintained at 6.7 mm in electrolysis. Additional stirring was done with a 16 × 30 mm (diameter × length) Teflon spindle-shape magnetic stir bar powered by a Stirrer (Model PC-101; Corning Inc., Acton, MA, USA) at speed setting 1.2, which was approximately 200 rpm. Electrolysis parameters and electrolyte properties were monitored during the electrolysis process.

Table 1 – A comparison of major elements, and some pollution indicative compositions and properties of surface seawater and deep ocean water samples.

Category	Item	Surface seawater	Deep ocean water
Major element (mg/L or kg)	Chloride	19,060–19,860	18,840–19,510
	Sodium	11,320–11,500	11,380–11,430
	Magnesium	1327–1330	1283–1320
	Calcium	400–441	400–432
	Potassium	400–414	390–421
Composition	Nitrite (μM)	0.08–0.11	<0.02
	Chlorophyll a (μg/L)	0.12–0.19	<0.03
Property	Temperature (°C)	22.5–23.8	9.4–10.2
	pH	8.10–8.20	7.56–7.70
	Salinity (psu)	34.2–34.5	33.6–34.0

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