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Electrolyzed Water Applications in Aquaculture and the Seafood Industry

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Introduction

Producing the safer food products not only can decrease the risk of foodborne illnesses outbreak, but also can increase their shelf life, market acceptability, decrease loss and waste and result in greater profitability for aquaculture producers and retailers. Shelf-life extension is achieved through the use of refrigeration and chemical additives, howeverboth thermal and non-thermal processing methods are also used to increase shelf-life and improve product safety by reducing the levels of pathogenic and spoilage microflora. However, thermal processing has severe negative influences on the quality of the products such as shrinkage, cook loss, color changes, texture, nutrition loss, and taste. Hence, applying non-thermal methods such as gamma irradiation, high pressure, UV, and electrolyzed water (EO water) provide interesting methods for food shelf-life extension as well as other food processing applications. Among these methods, EO water has garnered greater interest as a disinfectant in medicine and dentistry with newly developed applications from these medical fields for disinfection of cutting boards, gloves, contact surfaces, and animal care facilities where EO has proven to be effective. From this, new application in aquaculture and the seafood industry are being evaluated.

Electrolyzed water is a novel technology developed in Japan and it is based on electrolysis of water containing a low concentration of sodium chloride (0.1%) in an electrolysis chamber where anode and cathode electrodes are separated by a diaphragm or electrolytic cell. After electrolysis, at the anode, the water is acidic with a pH of 2.7 or lower, an oxidation-reduction potential (ORP) greater than 1,100 mV, and available chlorine concentration (ACC) of 10 to 80 ppm.At the cathode, the alkaline EO water has a pH of 11.6, ORP of -795 mV with no chlorine generated. The properties of the acidic and alkaline EO waters, depend upon the salt concentration, electrolysis time, and water flow into the electrolysis chamber.

One of the major applications in aquaculture is to treat surface waters from coastal watersheds or rivers used to supply water for the aquaculture facility which might be contaminated with pathogenic bacteria or viruses. This would be a particularly important application for fish hatcheries because of the high bactericidal properties of EO.

Another application would be to sanitize wastewater discharged from aquaculture production discharge into the environment before release. Studies show that using EO water decreases a number of pathogens including *Vibrio anguillarum*, *Aeromonassalmonicida*, *Escherichia coli*, Yellowtail ascites virus (YAV), and hiramerhabdovirus (HIRRV) up to 99.99% in 1 min. In 2006, researchers at Oregon State University, used EO water containing 30 ppm ACC to determine the inactivation of *V. parahaemolyticus*, and *V. vulnificus*in inoculated live oysters following an 8 h exposure. They reported 1.13 and 1.05 log CFU/g reduction for *V. parahaemolyticus*, and *V. vulnificus*,respectively within 6 h.

Recently, in our lab at Washington State University, we applied the EO water with 10 and 20 ppm ACC to treat live clams (*Venerupis philippinarum*) and blue mussel (*Mytilus edulis*) which were inoculated with *V. parahaemolyticus*, *A. hydrophila*, *E. coli* 104:H4, *Listeria monocytogenes*, and *Campylobacter jejuni* for a long enough period of time for these microbes to adhere to the exposed surfaces and also to become a component of the digestive system at a concentration of up to 8 logs. After exposure of the live shellfish to 45 and 90 min to acidic EO water, 2 to 3 log CFU/g reduction were observed with no chlorine residue found in the edible portion showing that EO water can be a safe, inexpensive, and effective method for shellfish producers to depurate shellfish and guarantee a safe food for their consumers. EO water is also effective for controlling the dinoflagellates responsible for paralytic shellfish poisoning, *Alexandriumminutum*, *A. catenella* and *Gymnodiniumcatenatum* showing that both toxic dinoflagellates can be killed and the toxins can be oxidized.

Other aquaculture and seafood applications for EO water include surface sanitation of salmon fillet, tilapia, tuna, stainless steel surfaces containing fish residue, ceramic tile, cutting boards, and gloves. For example, researchers showed that usingEO water (pH of 2.6, ORP of 1150 mV and ACC of 90 ppm) at 35ºC for 64 min for raw salmon fillet resulted in a 1.07 log CFU/g (91.1%) in *E. coli* O157:H7 and 1.12 log CFU/g (92.3%) reduction of *L. monocytogenes*, respectively. EO water containing 50 ppm and 100 ppm ACC combined with CO gas treatment enhanced the hygienic quality and freshness for tuna steaks extending refrigerated shelf life. The effectiveness of EO water on microorganisms depends upon different parameters including

1. Microorganisms: The effectiveness of EO water for inactivating microbes varies. *E. coli* O157:H7 tends to be much more sensitive to EO water compared to *L. monocytogenes* which might be due to the difference in cell wall structure of Gram-negative and Gram-positive bacteria. Recently, in our lab, we found other parameters also influence the bacteria responses to EO water. For example, *E. coli* O104:H4 was more resistant than *L. monocytogenes* to EO water which is because of the horizontal gene transfer in *E. coli* O104:H4 which makes it more resistant to different antibiotics compared to E. coli O157:H7.
2. The EO water properties: Acidic and alkaline EO waters have different chemical properties with acidic EO water being more effective compared to alkaline EO water. This may be due to the active chlorine present in acidic EO water and high OPR around 1,100 mV in addition to the low pH. The optimum condition for most of the bacteria is +200 to +800 mV. Hence, any changes in optimum conditions for microorganisms can depress their growth. However, a combination of alkaline

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and acidic EO water application, showed enhanced microbial inactivation, so sequential treatment may be beneficial in some situations.

3. Temperature: Most research on EO water application has been conducted at room temperature. However, by increasing the temperature of EO water up to 50°C a significant increase in microbial inactivation can be achieved, which may be suitable for sanitation of food contact surfaces, but not advisable for seafood products.

4. Exposure time: One of the most important factors influencing the efficacy of EO water on bacteria is application time. Some researchers report they could completely inactivate bacteria in less than 1 min. However, most other researchers report much longer treatment times required for complete inactivation of the same bacteria. This reflects differences in the properties of EO water along with the effect of different matrices in which the bacteria are present.

5. Organic matters: EO water contains available free chlorine which can react with organic matter including microorganisms so EO has less bactericidal effect on bacteria when substantial quantities of organic matters is present For example, EO inactivation of *V. parahaemolyticus* in a cell suspension (with no other organic matter) compared to the same concentration of bacteria in abacterial growth media found that the efficacy of EO water is significantly higher on cell suspension compare to cell culture. For example, for a 1 mL cell suspension, 19 mL EO water was needed for complete inactivation, but five times as much EO was required for the same microbes at the same concentration in a microbial media (1 mL cultured cell:99 mL EO water), for complete inactivation indicating that more EO water and a longer treatment time would be needed to inactivate bacteria in foods compared to many of the experimental systems tested

In conclusion, EO water is effective for shelf-life extension for aquatic foods including live shellfish, and for sanitizing water and food contact surfaces. A combination of EO waters (sequential treatment with alkaline and acidic EO) or in combination with other methods can extend shelf life. The US Environmental Protection Agency (EPA) approved EO for water treatment in the food industry making applications in aquaculture possible with little added regulatory approval.