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Mini Review

Characteristics and use of electrolyzed water in food industries

Athayde, D.R., Flores, D.R.M., Silva, J.S., Silva, M.S., Genro, A.L.G., Wagner, R., Campagnol, P.C.B., Menezes, C.R. and *Cichoski, A.J.

Food Science and Technology Post-graduation course, Rural Sciences Centre, Federal University of Santa Maria (UFSM), Roraima Avenue, n. 1000, Postal 97105-900, Santa Maria, Rio Grande do Sul, Brazil.

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Abstract

Electrolyzed water (EW) is a new technology that emerged in the last years with potential application in foods, mainly in microbiological aspects, with variation in application modes, dipping the food in solution, where variation of time can be changed and be apply in the form of spray. Because EW characteristics, its action in microorganisms are still been studied for mechanism elucidation and possible damages, as well its influence in the intrinsic characteristics of food, like color and oxidation. This unconventional or 'green' technology has the purpose to prove microbiological quality of food and decrease the use of natural resources like water with minimal generation of chemical/toxic residues. More studies are necessary in relation to this technology and its possible applications in food industry, as well characteristics and mechanisms.

Introduction

Current environment scenario is directed to rational use of natural resources. Emerging technologies have characteristics of decrease consumption of energy and water. The concept of this technologies is minimize or not produce chemical residues, and still have potential to many different uses, including in food industry. The search of alternative to conventional technologies have the objective of improve food as well microbiology, physic-chemical and the food quality. Electrolyzed water technology have one or more that premises of green chemistry (Proctor, 2011).

EW can be a technology with various applications in food industries, because adaptations are possible, with easily production, and little modifications are necessary to places where water is already used. This review presents basic aspects like composition, advantages and disadvantages, mechanisms, uses, and some tendencies of EW in food industries.

Development

Electrolyzed water: production and chemistry

The electrolysis of water and EW making process occurs when a sodium chloride brine (or other salt with chlorine) pass through a electrolysis cell with two poles: anode (+) and cathode (-), with or without membrane (Huang *et al*., 2008; Cui *et al*., 2009). Systems with membrane division can result in two types of water: acidic electrolyzed water (AEW) from anode side and basic electrolyzed water (BEW) from cathode side (Huang *et al*., 2008; Cui *et al*., 2009). The mains products in anode are Cl_2 dissolved, hipochlorous (HOCl) and hydrochloric acid (HCl), and in the cathode is sodium hydroxide (NaOH) and H_2 dissolved. Anode produces water with sanitizer characteristics and cathode produces water with cleaning properties, mainly because Cl_2 (and HOCl) and NaOH respectively.

The objective of membrane in the electrolysis equipment is separate two different types of EW, through migration of Na^+ (cation) to the cathode side, and Cl^- (anion) to the anode side. This characteristics of EW are showed in Table 1.

Table 1. AEW and BEW characteristics of pH and ORP. Adapted from Cui *et al*, 2009; Huang *et al*, 2008.

Type of water	pH	Oxidation-reduction potencial (ORP) (mV)
AEW	2-3	>1000
BEW	>10	< -700

According to Table 1, AEW presents low pH and high ORP, and this can be explained by HCl, Cl_2 and HOCl presence. In BEW, high pH and low ORP

*Corresponding author.
Email:*cijoale@gmail.com*

can be explained by diluted NaOH and H_2, as well a little fraction of hypochorite (OCl^-), because chlorine forms changes according to pH (Rahman *et al*., 2010). Other important parameter that influences the effect of EW together pH and ORP is free chlorine concentration (FCC). When the chlorine content increase, bactericidal activity is higher (Park *et al*., 2004).

Slightly acid electrolyzed water (SAEW) is the third type of EW that can be obtained by electrolysis of a brine. SAEW is a product of electrolysis without membrane presence or with membrane and AEW and BEW mixed in different proportions, according to proposed objectives. Guentzel *et al*. (2008) related the characterization of SAEW with pH approximate of 6,0-6,5 and ORP 800-900 mV. In this range of pH, 95% of chlorine form in water is HOCl, 5% is OCl^- and traces of Cl_2 (White, 2010).

HOCl is important because chlorine in Cl_2 form can volatilize (Cui *et al*., 2009), and the efficacy against microorganism can be lost. So, neutral pH is a good characteristic against chlorine evaporation, maintenance of HOCl concentration and activity of SAEW in microorganisms (Len *et al*., 2002), because it is the most germicide form of chlorine in solutions, having sanitizing activity 80 times more efficient than OCl^- at equivalent concentrations (Eifert and Sanglay, 2002). Moreover, SAEW is non-corrosive, more stable than AEW in storage conditions and less dangerous to worker health (Cao *et al*., 2009).

Some factors can interfere in EW production, like water flow. It can change FCC and ORP in inverse proportion. Salt concentration of brine affect in direct proportion with FCC and electric conductivity. Temperature has little influence in EW parameters (Hsu, 2005). Total chlorine is the group with all forms like chlorohydrins (fatty acids), chloramines and free chlorine (HOCl, OCl^-, Cl_2) (White, 2010). Free chlorine have bigger activity than chloramines (Gottardi *et al*., 2013), although exist in solutions with organic matter all these forms, generally the FCC is analysed.

In works exist a wide range of FCC applied, which can be since 0,1 to more of 100 mg/L of Cl_2 (Fabrizio and Cutter, 2004; Cao *et al*., 2009; Guentzel *et al*., 2010; Quan *et al*., 2010; Ding *et al*., 2011; Issa-Zacharia *et al*., 2011; Rahman *et al*., 2011; Arévalos-Sanchéz *et al*., 2012; Feliciano *et al*., 2012; Al-Holy and Rasco, 2015; Martínez-Hernández *et al*., 2015). It means that low concentration of chlorine can be active in bacteria, but in this cases other parameters must be adjusted, like dipping time (Arévalos-Sanchez *et al*., 2013; Al-Holy and Rasco, 2015) or amount of water and pressure in spray (Northcutt *et al*., 2007). The combination of EW with other chemical substances applied together was also study (Arévalos-Sanchez *et al*., 2012; Chen *et al*., 2015; Mansur *et al*., 2015). In places where water is already used, a little number of modifications in the water system are needed.

High FCC must be used in a caution way, because chlorine is dangerous to health of workers, causing damage to respiratory tract (when gas evaporate), irritation to skin (direct contact) and others (WHO, 2000). A range of FCC must be determined together with pH for better action in microorganism as well as application form.

Advantages and disadvantages

In the concept of EW, main advantages are the use of a brine to production, and possibility of local obtainment (Al-Haq *et al*., 2005; Huang *et al*., 2008). Other advantages are safety of EW at neutral or basic pH, when HOCl or OCl^- are present respectively (White, 2010) that have good action in microorganisms and low capacity of evaporation. Other advantage is a big number of applications, like spray, ice and dipping food in EW. EW can be prepared relatively quickly and easily, with low production cost, avoid chemical products transportation, storage and environmental risk. New technologies have the advantage of new and innovative possibilities of use.

The amount of information about new technologies generally is a problem, specially the absence of them. EW have disadvantages like evaporation of Cl_2 and loss of activity, mainly at lower pH. Along electrolysis, Cl_2 and H_2 are produced (Huang *et al*., 2008), and this can affect worker health, like respiratory tract, besides fact of explosion in higher concentrations. Application time is other disadvantage factor, because the longer the time, better the activity in microrganism. A disadvantage is the initial cost of equipment, which is generally high. Because the interactions of chlorine with proteins and fats, organic matter can cause decrease in EW activity (Cressey *et al*., 2008).

Action mechanisms of EW

Actually, isn't a consensus about EW mechanism, but exist a lot of theories. ORP of AEW can cause damage to *E. coli* O157:H7 on bacterial ORP and attack inner and outer membranes, causing necrosis of cells (Liao *et al*., 2007), with damage verified with microscopy (Feliciano *et al*., 2012). SAEW have equal or higher activity in bacteria than AEW or sodium hypochlorite (NaOCl) at same concentrations and FCC (Cao *et al*., 2009) with advantage of few free chlorine (Rahman *et al*., 2012). HOCl can change bacterial respiration destroying the electron transport chains and affecting adenine nucleotide pool (Albrich *et al*., 1981).

Chlorine can affect microorganisms by inhibiting carbohydrates metabolism enzymes that have sulfhydryl groups sensitive to chlorine, and this blocked glucose oxidation. (Eifert and Sanglay, 2002). One or more mechanisms are responsible by EW activity in microorganisms. Inactivation of key-enzymes, nucleic acid damage, the wall and other vitals can be affected (White, 2010). AEW candecrease dehydrogenase activity of Escherichia coli and Staphylococcus aureus, and change membrane permeability, increasing conductivity, decreasing intracellular ADN and potassium ions (Zeng *et al*., 2010).

The concentration of OH- present in AEW and SAEW can be one point of fungicidal efficiency, because OH- can damage the normal structure of conidia, destabilizing your ionic equilibrium (Xiong *et al*., 2010). However, chlorine form is fundamental in disinfection capacity of AEW and SAEW, instead OH- radical (Hao *et al*., 2012). AEW activity is attributed to HOCl, indirectly, because after HOCl permeation in bacterial cell, the radical OH- is generated (Mokudai *et al*., 2012; Mokudai *et al*., 2015).

EW applications in food industries

EW is utilized in various types of foods, generally with microorganisms action. Some AEW parameters was studied in *Vibrio parahemolyticus* and *Listeria monocytogenes* in shrimps storage at different temperatures (Xie *et al*., 2012). Others studies with *Vibrio parahemolyticus* were performed in shrimps (Wang, Sun, Jin *et al*., 2014; Wang, Zhang, Li *et al*., 2014), besides *Vibrio parahemolyticus*, Quan *et al*. (2010) studied SAEW action in *Vibrio vulnificus*, and compared effects of EW to sodium hypochlorite. The effect of EW in *E. coli* and *Salmonella* spp.present in freeze shrimp was studied, as well increasing quality (Loi-Braden *et al*., 2005). AEW in ice form was studied on shrimp quality preservation (Lin *et al*., 2013), in the dark conditions, where AEW ice is a good inhibitor of polyphenol oxidase enzyme, that cause melanosis and decrease in acceptability (Wang, Lin, Li *et al*., 2014).

Histamine-producing bacteria load was reduced in food preparation surfaces and fish skin after EW in liquid and ice forms was used (Phuvasate and Su, 2010). AEW was studied in objects related to food preparation in intermittent spray application to reduce or prevent bacterial biofilm formation (McCarthy and Burkhardt III, 2012). EW action on fish fillets and in the water collected from the melted ice (Feliciano *et al*., 2010) and *Listeria monocytogenes* in cold-smoked Atlantic salmon after pretreatment with AEW was also studied (Shiroodi *et al*., 2016).

EW activity in pork (Brychcy *et al*., 2015; Mansur *et al*., 2015), and in ready-to-eat meats with *Listeria monocytogenes*, *Salmonella* Typhimurium, *Campylobacter jejuni* was compared to 2% lactic acid and hypochlorite solutions (Fabrizio and Cutter, 2004). Action of EW by soaking fish, chicken and beef surfaces with E. coli, *Salmonella* and *Listeria monocytogenes* was evaluated (Al-Holy and Rasco, 2015). *Listeria monocytogenes* and *Salmonella* Typhimurium in chicken breast meat was studied with dipping treatment (Rahman *et al*., 2012b). Other bacteria studied was *Pseudomonas* spp when SAEW was applied on fresh cut vegetables (Pinto *et al*., 2015).

Application of EW was applied on several vegetables like spinach and lettuce (Guentzel *et al*., 2008), carrots (Rahman *et al*., 2011), mushrooms (Ding *et al*., 2011), minimally processed apples (Graça *et al*., 2011), fresh ready-to-eat vegetables and sprouts (Issa-Zacharia *et al*., 2011), peaches and grapes (Guentzel *et al*., 2010), cilantro (Hao *et al*., 2015), broccoli (Martínez-Hernández *et al*., 2015).

BEW have capacity to remove *S. aureus* biofilm compared to 2% of NaOH, and AEW have bactericidal effect compared to 2% of HCl (Sun *et al*., 2012). BEW is a important EW, because it have clean properties and AEW can affect bacteria (Sun *et al*., 2012) with a possible synergistic effect. In general way, the application potential of BEW is less studied than acid fractions.

SAEW have bactericidal activities and was efficient in reduce *Listeria monocytogenes* biofilms in stainless steel and glass (Arevalos-Sanchez *et al*., 2012). Action of EW was better than common sanitizers used in dairy industry higienization (Jiménez-Pichardo *et al*., 2016).

EW affect *Aspergillus flavus* (Xiong *et al*., 2010), *Candida albicans* (Zeng et *al*., 2011), *Botrytis cinerea* and *Moniliniafructicola* (Guentzel *et al*., 2010), Fusarium spp. (Audenaert *et al*., 2012). AEW still decrease aflatoxin B1 concentration in peanuts (Zhang *et al*., 2012), SAEW can trigger deoxynivalenol biosynthesis (Audenaert *et al*., 2012).

EW was efficient to reduce pesticide residues of acephate, omethoate and dimethyl dichlorovinyl phosphate in vegetables without affect vitamin C content without loss in nutritional values (Hao *et al*., 2011). The increase of the flavor of persimmon wine was obtained with EW (Zhu *et al*., 2016).

Conclusion

EW is a emerging technology and its main use is food microbiology, because in literature, good results was founded with this objective. A great number of mechanisms are related and the effect was based in one or more ways evolving chlorine species, ORP and others, to targets bacterial enzyme, membrane damage and others. Type of application (spray, dip, or others), pH, FCC, ORP, amount of water, temperatures, dipping time and others are just some variables that can be combined to find the better results of EW application. Generally, AEW and SAEW are utilized, but BEW can have good actions in food, by the way this water is less studied than acid fractions. EW have vantages and advantages, and is important to understand the better way of application and characteristics of this technology with high potential to use in food industry.

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