

Applications of electrolyzed water

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As the situation of severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2) is still de-teriorating, there has been a huge increase in the demand and use of disinfectants. Electrolyzed water (EW), as a novel broad-spectrum disinfectant and cleaner, has been widely used for several years.

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1. Introduction

The Center for Disease Control and Prevention (CDC) has recently reported that there is at least one person who has a healthcare-associated infection in every 31 hospital patients in any given day ^[1]. Such healthcare-associated infections (HAI) include central line-associated bloodstream infection, catheter-associated urinary tract infections, surgical site infection and ventilator-associated pneumonia ^[2]. HAIs are a major cause of morbidity and even mortality in the United States ^[3]. The healthcare environment is a primary source of pathogenic microorganisms ^[4]. Molds may be present on wet or damp surfaces or materials ^[5]. Bacteria may also be present in bathroom installations, including sink drains and ice machines. Furthermore, surgical site infections can sometimes be superficial infections involving the skin ^{[6][7]}. At the same time, infections in other surgical sites could be more serious, which may involve tissues under the skin, organs, or even implanted materials ^{[8][9]}. Infections also increase the length of stay, readmission rates, costs, and even mortality ^{[10][11]}. Biofilms are responsible for causing 80% of human infections. The National Institutes of Health (NIH) reported that biofilms are responsible for up to 80% of human bacterial infection ^[12].

Therefore, developing effective disinfectants and antiseptics for killing pathogens and destroying the biofilm formation in the environment and human healthcare is one of the most significant steps for infection prevention and control. The medical industry has employed a number of decontamination techniques throughout the hospital and healthcare clinical field ^{[13][14][15]}. However, some of these techniques have disadvantages such as high cost, low efficacy, remaining chemical residues, and adverse effects irritation on the human skin ^{[16][17]}. As an important premise for practical application, it should have high antimicrobial efficacy and no toxicity to the human body ^[18].

Electrolyzed water (EW) is a novel disinfectant and cleaner which has been widely used in the food industry for several years to ensure the sterilization of surfaces and safety of food ^{[19][20][21][22]}. EW is produced in an electrolysis chamber which contains dilute salt and tap water without any harmful chemical addition ^[23]. EW has antimicrobial effects against a variety of microorganisms including common biofilm, viruses, bacteria, spores and fungi in chronic wounds and environmental surfaces ^{[24][25][26][27][28][29]}. Currently, due to its beneficial properties

(anti-infection and cell proliferative), researchers pay more attention to the application of electrolyzed water in clinical treatments including medical sterilization. The US Environmental Protection Agency (EPA) recommended the use of disinfectants with hypochlorite acid as active ingredients for the disinfection of surfaces against COVID-19 [30]. Furthermore, various studies have been carried out on the antimicrobial activity of EW against different illnesses, including diabetic foot ulcers [31][32], venous ulcers in the legs [33][34] or feminine hygiene [35][36].

However, some studies have reported that the application of EW is limited by factors such as the corrosion of equipment which is in contact with acidic or basic EW and the ability of organics materials (proteins, lipids and so on) to shorten its shelf life [37][38]. To overcome these defects, hurdle technology, which is a combination of two or more low-dose disinfection and preservatives techniques could be applied [39]. Therefore, EW combined with other disinfection methods could be an effective way to obtain a desirable result [40][41].

The aim of this review was to introduce recent developments and provide a new perspective with EW in the clinical field. Many characteristics of electrolyzed water in this review article were introduced including the physiochemical properties, history, limitation principle, generation methodologies, and the impact of these characteristics on the sanitizing efficacy of EW. In addition, applications of EW for microbial control in the clinical field are also discussed.

2. Principles and History of EW

The development history of electrolyzed water can be traced back for more than a century [42]. The concept of electrolyzed water was first proposed in Russia [43]. However, it has been widely used for various purposes including disinfection, water regeneration and water decontamination in Japan since 1980. As time went by, its application has extended to other fields such as the food industry, agriculture, livestock management and clinical application [44][45][46][47]. Figure 1 illustrates the application of EW in different areas at different pH values.

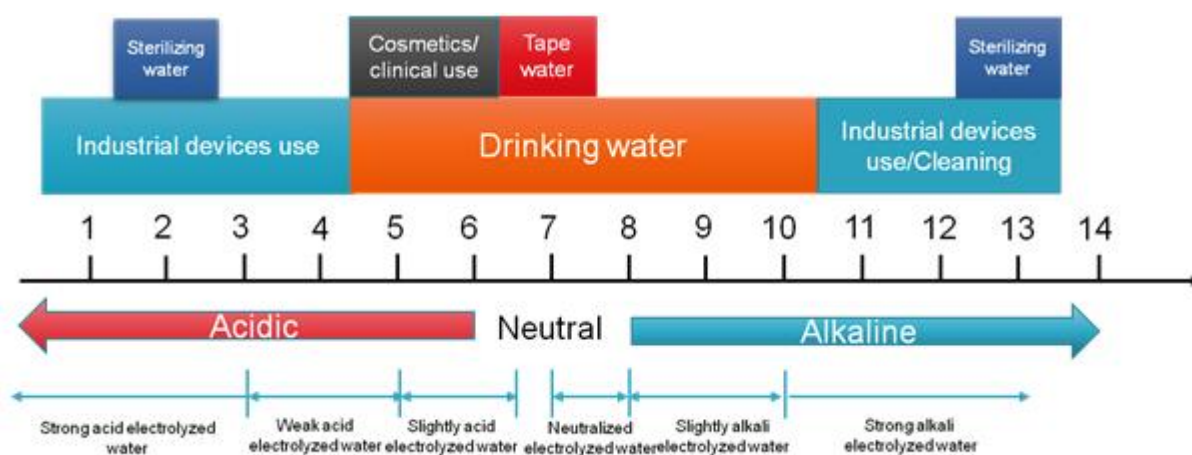


Figure 1. Application of electrolyzed water (EW) at different pH values in various fields.

Electrolyzed reduced water was invented in the early 19th century [48]. Research on electrolyzed water started in Japan around 1931 and its application and popularity to agriculture in the 1950s. In 1960, the water was applied to

medical care and in 1966, electrolyzed reduced water was touted as having “healing effects” including indigestion, chronic diarrhea, antacid, abnormal gastrointestinal fermentation, and hyperacidity [49]. A device for the preparation of ERW was authorized for home-use by the Ministry of Health, Labor, and Welfare of Japan [50].

In 1994, with the support of the Ministry of Health, Labor, and Welfare of Japan, the functional water foundation was established to promote the use of electrolyzed water in society. Based on considerable scientific evidence related to the risk assessment of EW, in 2005, the Drugs, Cosmetics and Medical Instruments Act of Japan was revised and re-authorized an ERW-producing device as a home-managed medical device. In 2002, the Ministry authorized the use of hypochlorous acid water on designated food additives. Recently, in 2017, the US Food and Drug Administration (USFDA) also authorized hypochlorous acid (electrolytically generated on-site) for use on food contact surfaces (FCS) [51]. In addition, Chinese standardization administration published a series of criteria in 2020, related to hypochlorous acid water, which can be used for human skin, hand and mucous membrane. Table 1 illustrates the criteria of application of EW in different countries.

3. Systems for Generation of Electrolyzed Water

Electrolyzed water (EW) is produced in an electrolysis chamber which contains hydrogen chloride (HCl) solution or dilute salt (NaCl) [52]. According to the different devices, electrolyte and electrolysis conditions, EW can be classified into the following categories: acidic electrolyzed water, neutral electrolyzed water and alkali electrolyzed water [53]. The characteristic of EW is shown in Table 2. The application of EW can be roughly divided into alkali water for drinking and electrolytic water for cleaning, sterilization, and disinfection [54][55][56].

These solutions are produced by the electrolysis of dilute salt (NaCl) passing through two or three cell electrolyzers with the anode and cathode separated by a diaphragm. It can produce two types of water simultaneously. Acidic electrolyzed water (AEW), with a pH of 2 to 3, available chlorine concentration (ACC) of 10 to 90, and oxidation–reduction potential (ORP) >1100 Mv, is produced at the anode side. At the same time, basic electrolyzed water (BEW) with a pH of 10 to 13, and ORP from –800 to –900 Mv is generated at the cathode side. Nowadays, there are some novel forms of electrolyzed water such as slightly acid electrolyzed water (SAEW), weak acid electrolyzed water (WAEW) and neutral electrolyzed water (NEW) [57][58][59]. SAEW is very popular in Japan, China and Korea [60][61][62]. SAEW (pH of 5.5–6.5, ACC of 10–80 ppm and ORP of 800–900 Mv), and NEW (pH of 7–8 and ORP of 750–900 Mv) are produced by using single-cell chambers. SAEW is produced by the electrolysis of HCl alone or combined with NaCl in a single-cell unit (without diaphragm) [63]. It is expected that the SAEW will not lose its superior features after mixing due to the unipolar reaction in the process of electrolysis. In addition to the above method, NEW can also be produced by a mixture of the anodic solution with OH[–] ions [64]. The details are shown in Figure 2. EW can also be stored in containers of special materials or converted into ice cubes for future use [65].

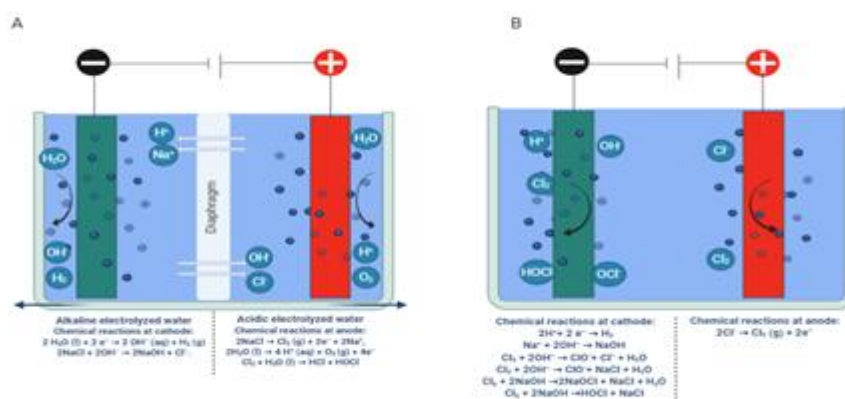


Figure 2. Generation of electrolyzed water. A: alkaline electrolyzed water and acidic electrolyzed water; B: slightly acidic electrolyzed water. Created with BioRender.com.

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