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REVIEW

Electrolyzed water and its application in animal houses

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Abstract Electrolyzed water (EW) can be produced by electrolysis of a dilute salt solution. Slightly acidic electrolyzed water (SAEW, pH 5.0–6.5) and neutral electrolyzed water (NEW, pH 6.5–8.5) are considered healthy and environmentally friendly because no hazardous chemicals are added in its production, there is reduced corrosion of surfaces and it minimizes the potential for damage to animal and human health. Over the last decade, EW has become increasingly popular as an alternative disinfectant for decontamination in animal houses. However, there have been some issues related to EW that are not well known, including different mechanisms for generation of SAEW and NEW, and the antimicrobial mechanism of EW. This review covers the definitions of SAEW and NEW, different generation systems for SAEW and NEW, the antimicrobial mechanism of EW, and recent developments related to the application of SAEW and NEW in animal houses.

Keywords disinfection, poultry and livestock, slightly acidic electrolyzed water, neutral electrolyzed water

1 Introduction

The environment within animal houses is often contaminated with pathogenic microorganisms and contaminated surfaces in such facilities may act as reservoirs for pathogenic microorganisms[1–3]. Exposure to high levels of airborne microbes in animal houses can have negative impacts on the health of both the animals and the workers[4–7]. Microorganisms contaminating animal houses are also responsible for disease infection among animals[8,9] and can even enter the food chain[10,11]. Provision of healthy environments for animal production is receiving increased attention.

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Disinfection is a commonly recommended approach for disease prevention in animal houses[12–15]. This can help to lower the potential for disease infection and transmission in animal houses by reducing the population of pathogenic microorganisms on the surfaces or in the air. Numerous chemical disinfectants such as benzalkonium chloride, formaldehyde and glutaraldehyde are used for disinfection against bacterial infections in animal houses[16]. However, the use of these chemical disinfectants has limited potential due to their toxicity, corrosiveness and/or volatility[17]. Also, the resistance and cross-resistance of pathogens to chemical disinfectants has been reported[18,19]. Therefore, it is essential to develop alternative disinfectants for decontamination in animal houses.

Electrolyzed water (EW) has been regarded as a novel sanitizer in recent years. Acidic electrolyzed water (AEW, pH < 2.7), slightly acidic electrolyzed water (SAEW pH 5.0–6.5) and neutral electrolyzed water (NEW, 6.5–8.5) are the three main types of EWs reported as alternative disinfectants for decontamination. AEW has been reported to be an effective antimicrobial agent in the food industry[20–22]. However, AEW can easily release Cl_2 gas due to its volatility, which causes chlorine loss, thus decreasing AEW bactericidal activity over time[23,24]. The strong acidity (pH < 2.7) of AEW can also cause corrosion of equipment[25]. These disadvantages potentially limit the use of AEW in some applications such as animal houses. In contrast, SAEW and NEW are near neutral pH and more stable than AEW[24]. They have been increasingly used for the prevention and control of microorganisms[22,26–28]. SAEW and NEW are considered healthy and environmentally friendly because no hazardous chemicals are added in its production, they cause less corrosion of surfaces and minimize the potential for damage to animal and human health[25,29,30]. For these reasons, SAEW and NEW may be alternative disinfectants for decontamination in animal houses. A considerable number of studies have reported the increased use of SAEW and NEW for controlling contamination in animal houses, including facilities for swine, poultry and diary[1–3,15,31–35]. This review covers some important aspects of SAEW/NEW, including definition, generation, microorganism inactivation and applications in animal houses.

2 Electrolyzed water (EW)

Electrolyzed water (EW) was initially used for inactivation of pathogens in health care facilities in Japan. AEW, also known as electrolyzed oxidizing water, is produced by electrolysis of a dilute salt solution in an electrolytic cell, within which the anode and cathode are separated by a membrane. By subjecting the electrodes to direct current voltages, negatively charged ions such as chloride and hydroxide move to the anode to give up electrons and become gaseous oxygen (O_2) and chlorine (Cl_2), hypochlorite ions (OCl^-), hypochlorous acid (HOCl) and hydrochloric acid (HCl). Concurrently, positively charged ions, such as hydrogen and sodium, move to the cathode to take up electrons and become hydrogen gas (H_2) and sodium hydroxide (NaOH)[36]. As a result, AEW with low pH and available chlorine is produced at the anode. Alkaline EW, also called electrolyzed reduced water with high pH (10.0–11.5) is produced at the cathode. The principle of producing AEW can be described with the following:

$$\text{Anode}: \ 2H_2O - 4e^- \rightarrow 4e^+ + O_2\uparrow$$

$$2Cl^- - 2e^- \rightarrow Cl_2\uparrow$$

$$Cl_2 + H_2O \rightarrow H^+ + Cl^- + HOCl$$

$$HOCl \rightarrow H^+ + OCl^-$$

$$\text{Cathode}: 2H_2O + 2e^- \rightarrow 2OH^- + H_2\uparrow$$

Scientists have given various names to EW with a pH of 5.0–6.5, but none of these names has been universally adopted. Most studies have defined EW with a pH of 5.0–6.5 as SAEW[1–3,15,28,33,37–57]. However, it has also been called electrolyzed neutral water [58], near-neutral electrolyzed oxidizing water[25,59] and NEW[24,48,60,61]. It is important to distinguish SAEW and NEW using an agreed standard. In this review, EW with a pH of 5.0–6.5 and 6.5–8.5 are defined as SAEW and NEW, respectively.

Available chlorine, also called free chlorine, has been considered to be the active component of EW responsible for its bactericidal activity. The pH of EW is important in the formation of various chlorine species. The relative levels or proportions of available chlorine compounds (Cl_2, HOCl and OCl^-) in EW are pH dependent[21,23,38]. Bactericidal activity of HOCl is much higher than that of OCl^-[21,38]. The highest proportion of HOCl of EW was found to be generated at around pH 4–5. More Cl_2 was generated from HOCl at a lower pH, whereas more OCl^- was generated from HOCl at a higher pH[23]. At pH 5.0–6.5, the effective form of chlorine in SAEW is mostly HOCl, which has been shown to have strong antimicrobial activity[30,37,62]. For NEW with pH 6.5–8.5, the effective form of chlorine is mainly OCl^-. Therefore, SAEW was reported to have a higher bacterial activity than NEW at the same available chlorine concentration (ACC)[46]. The available chlorine and its proportion in SAEW and NEW is considered to be the main factor affecting their antimicrobial activity.

3 Generation systems for SAEW and NEW

The principles of producing SAEW and NEW are the same as AEW, but their generation systems are modified to reach the desired pH. SAEW has been reported to be produced by electrolysis of dilute NaCl and/or hydrochloric acid solutions in an electrolysis cell without a membrane[15,38,63], or by redirecting the product formed at the cathode into the anode chamber while electrolyzing a dilute NaCl solution in a cell with a separating membrane[25]. NEW has been reported to be produced by electrolyzing a dilute NaCl solution in an electrolysis cell without membrane with or without dilution with tap water after electrolysis[27,32], or by redirecting the product formed at the cathode into the anode chamber while electrolyzing a dilute NaCl solution in a cell with a separating membrane[64]. Production systems for generating SAEW and NEW described in previous studies are shown in Table 1.

One common system is to generate SAEW by electrolysis of a dilute HCl solution in a non-membrane electrolytic cell, then the highly concentrated HOCl produced is diluted with tap water[38]. The electrolyte in this system is a dilute HCl solution, but a NaCl solution can also be used as the electrolyte[39,45,63]. The SAEW generated in this system usually has a low ACC (5–50 $mg\cdot L^{-1}$, preferably 20–30 $mg\cdot L^{-1}$), but most of the available chlorine is present as HOCl[24,38,46]. This system has been widely employed to generate SAEW with a low ACC for decontamination in the food industry. Another system is to generate SAEW by electrolyzing dilute NaCl and HCl solutions in a non-membrane electrolytic cell. In this system, NaCl provides most of the Cl^- to generate available chlorine, and HCl is mainly to adjust the pH to 5.0–6.5. HCl solution can also be added after electrolyzing a dilute NaCl solution to adjust the pH[33,79,80]. Zheng et al.[46] reported that the available chlorine composition was similar for SAEW generated by adding HCl solution either before or after electrolyzing a dilute NaCl solution. Using this system, SAEW with a large range of ACC was generated, from 0.5 to 400 $mg\cdot L^{-1}$ [1,2,15,41,54,68,69]. NEW is produced when a dilute NaCl solution is electrolyzed in a

Table 1 Types of generation systems for SAEW and NEW

Electrolyzed water	Electrolyte/Electrolytic cell	Generation mechanism	References
SAEW	HCl/Non-membrane	Dilute HCl or NaCl solution is electrolyzed in a non-membrane electrolytic cell to produce highly concentrated HOCl, which is then diluted with tap water.	[28,37,38,40,43,44,47,51–53,55,57,65–67]
SAEW	NaCl and HCl/Non-membrane	Dilute NaCl and HCl solution is electrolyzed in a non-membrane electrolytic cell.	[1,2,15,41,54,61,68,69]
NEW	NaCl/Non-membrane	Dilute NaCl solution is electrolyzed in a non-membrane electrolytic cell.	[60,70–73]
NEW	NaCl/Non-membrane	Dilute NaCl solution is electrolyzed in a non-membrane electrolytic cell to produce EW with highly available chlorine, which is then diluted with tap water.	[26,27,29,32,74,75]
SAEW or NEW	NaCl/Membrane	Dilute NaCl solution is electrolyzed in an electrolytic cell with a membrane. A certain proportion of the Alkaline EW formed at the cathode chamber is redirected into the anode chamber.	[25,34,46,64,76–78]

Note: SAEW, slightly acidic electrolyzed water; NEW, neutral electrolyzed water; EW, electrolyzed water.

non-membrane electrolytic cell. One system is to produce NEW with a desired ACC directly. The other system is to produce EW with highly concentrated available chlorine that is then diluted with tap water to NEW, as is done with chemical sanitizers. AEW is produced by electrolysis of a dilute salt solution in an electrolytic cell, within which the anode and cathode are separated by a membrane. This system for generating AEW can also be used to produce SAEW and NEW, by redirecting the product formed at the cathode into the anode chamber. SAEW or NEW is produced depending on the mixing proportion of the electrolyzed reduced water formed at the cathode and the AEW formed at the anode. Different systems can produce SAEW/NEW with different properties. Even at the same pH and ACC, the active components of EW can be different[46]. The generation mechanism can be an important factor affecting the active components of SAEW and NEW, and thus their antimicrobial activities.

4 Antimicrobial activities of SAEW and NEW

SAEW is promoted as a highly effective, healthy and environmentally friendly disinfectant for the food industry[25,37,38,44,81]. It has been reported to possess high antimicrobial activity against a broad spectrum of microorganisms, including *Bacillus cereus*[52], *Bacillus subtilis*[42], *Escherichia coli*[40,41,43,44,61,65,68], *Listeria monocytogenes*[45,67], *Salmonella enteritidis*[37,46,67,68], *Salmonella* spp[44], *Staphylococcus aureus*[40,41], *Vibrio vulnificus* and *Vibrio parahemolyticus*[81,82], mold and yeast[3], porcine reproductive and respiratory syndrome virus, and pseudorabies virus[49]. The antimicrobial activity of SAEW relies on its available chlorine, primarily HOCl, which has strong antimicrobial activity[23,30,46,62].

NEW has also been employed to inactivate a variety of microorganisms, including *Alicyclobacillus acidoterrestris* spores[78], *B. subtilis*[75], *E. coli*[26,29,46,72–75], *Erwinia carotovora*[27], *L. monocytogenes*[26,27,29,74], *Monilinia fructicola* and *Botrytis cinerea*[83], *Salmonella* spp[27,46,73,74], *S. aureus*[26,29], *Pseudomonas aeruginosa*[26,29], *V. vulnificus* and *V. parahemolyticus*[72], *Fusarium* spp[60]. and avian influenza viruses[84]. The antimicrobial activity of NEW relies on its available chlorine. Compared to SAEW, more available chlorine is present as OCl^- when HOCl is converted to OCl^- with an increased pH[46].

Bacteria can generally grow in the pH range of SAEW and NEW. The pH is important in the antimicrobial activities of SAEW and NEW, mainly by influencing the formation of various available chlorine species. Understanding the antimicrobial mechanism of EW is crucial to enable better utilization of EW as an antimicrobial agent. However, little information has been published to explain the antimicrobial mechanism of EW. In general, it is well known that available chlorine compounds are responsible for the antimicrobial activity of EW. Other oxidants, such as the reactive oxygen species (ozone and hydrogen peroxide), generated during electrolysis, are also considered to contribute to the antimicrobial activity of EW[85,86]. Some researchers have suggested that high oxidation-reduction potential (ORP) of AEW contributes to its high antimicrobial activity[87,88]. The oxidation, resulting from the high ORP of AEW, probably damages cell membranes and disrupts cell metabolic processes. However, SAEW and NEW have been employed to inactive a variety of microorganisms, even without a high ORP, such as AEW (ORP $>$ 1100 mV). Koseki et al.[89] reported that the higher ORP of ozonized water did not give a higher antimicrobial effect than the lower ORP of EW. This suggests that high ORP is not the determining factor in the antimicrobial activity of EW. It also has been noted that the low pH of AEW may reduce bacterial growth and sensitize the outer membrane of bacterial cells to the entry of active compounds[90,91].

Feliciano et al.[92] investigated the structural changes to *E. coli* and *Listeria innocua* cells treated with AEW and NEW by transmission electron microscopic analysis. Exposure to AEW and NEW decreased the integrity of the cell envelope and caused aggregation of the cytoplasmic components. Similar structural damage to *E. coli* O157:H7 and *S. aureus* by SAEW has been reported[41]. The research on disinfection mechanisms conducted by Zeng et al.[93] revealed that AEW could rapidly decrease the dehydrogenase activities of *E. coli* and *S. aureus*, resulting in inhibition of respiration and anabolism. AEW exposure can increase the membrane permeability of the cells and cause leakages of intracellular DNA, K^+ and proteins, and some intracellular proteins are destroyed. Several studies have shown that HOCl penetrates bacterial cell membranes and produces hydroxyl radicals[94–96]. These radicals are known to exert antimicrobial activity by causing the oxidation of key metabolic systems in bacteria[21]. Fukuzaki[97] developed a model to explain the antimicrobial mechanism of sodium hypochlorite. This model suggest that the antimicrobial activity of EW is governed by HOCl and OCl^-. The antimicrobial action of HOCl is attributed to its penetration into microbial cells across the cell walls and membranes. As a result, HOCl can attack the microbial cell not only from the outside, but also from within the cell. OCl^- is unable to penetrate the microbial cell membrane because of the existence of the lipid bilayer, but it can still impose oxidizing action from outside the cell. The microbial cell wall and membrane can thus be ruptured or disintegrated by exposure to OCl^-, following the inactivation of functional proteins localized in the plasma membrane. The inhibition of enzyme activity essential for microbial growth, damage to the membrane and DNA, and perhaps deterioration in membrane transport capacity are believed to be responsible for the antimicrobial activity of HOCl and OCl^-, although these factors have not been fully examined[22].

5 SAEW and application in animal houses

Animal houses are often contaminated with high concentrations of microorganisms which have multiple adverse environmental and health effects on both animals and workers. Removal of microbial contaminants in animal houses is receiving increased attention. In recent years, spraying or soaking using SAEW or NEW has been introduced to lower the microbial contaminant concentrations in animal houses to prevent diseases, mainly for surface and air disinfection. They are considered as alternative disinfectants for decontamination in animal houses because of their high antimicrobial activity, environmental safety, reduced corrosion of surfaces, and minimization of the potential for damage to animal and human health. SAEW is much more often employed for disinfection in animal houses than NEW.

5.1 Surface disinfection

Table 2 illustrates the effectiveness of SAEW in reducing the microbial populations on the surfaces in animal houses. Spraying or flushing using SAEW has proven to be highly effect in reducing microbial populations on the structural and equipment surfaces. Increasing the ACC of SAEW and the spraying or flushing volume can improve the antimicrobial effectiveness on these surfaces. Additionally, Zang et al.[98] reported that cleaning with tap water and spraying SAEW can inactivate *S. enteritidis* on the surface of plastic cages used for poultry transport. The inactivation activity increased with increasing cleaning time, treatment time and ACC of the SAEW. Spraying SAEW is also suggested to be a sanitizing solution for eggshells[37,50]. It is reported that SAEW has an equivalent or higher efficiency in reducing *E. coli* O157:H7, *S. aureus, S. enteritidis* and indigenous microbiota present on eggshells compared to chlorine dioxide and NaOCl solution, and has similar bactericidal activities with AEW at the same ACC (60–100 $mg \cdot L^{-1}$). Several researchers have reported that organic matter, such as protein compounds, can reduce the bacterial activity of EW[3,99–102]. Significant amounts of organic matter are usually attached to the structural and equipment surfaces in the animal houses. In addition to increasing the ACC of SAEW and the spraying or flushing volume, cleaning before disinfection can also be employed to improve the antimicrobial effectiveness for these surfaces.

5.2 Air disinfection

The sanitizing potential of spraying SAEW on airborne microbes in animal houses is shown in Table 3. The airborne microbial populations in poultry houses increase during in the day. This may be because the continuous movement of birds can lead to more microorganisms in the air[54]. The airborne microbial population after spraying SAEW is significantly lower than for the untreated control (Table 3). Spraying SAEW or NEW is suggested to be an efficient approach to reduce airborne bacterial contamination in layer poultry houses. The ability of spraying SAEW to reduce airborne bacterial contamination in a layer house showed a dosage-dependent relationship with the ACC of SAEW and the spraying volume[15,75]. Spraying NEW has also been reported to reduce airborne particulate matter to which microbes attach in a layer breeding house[32]. When comparing the change in airborne microbial populations after spraying SAEW or water in a layer chamber, Zheng et al.[33] demonstrated that airborne culturable bacteria were reduced more by the bactericidal effect of SAEW than by the reduction in airborne particular matter. In addition to the ACC of SAEW and the spraying volume,

Table 2 Antimicrobial effectiveness of spraying SAEW on surfaces in animal houses

Animal houses	Surface	Microbes	pH	ACC/(mg·L^{-1})	Treatment	Microbial concentration/(CFU·cm^{-2})		Reduction/%	Reference
						Before	After		
Layer breeding house	Floor	Culturable bacteria	6.2	250	Cleaning and spraying (120 mL·m^{-2} floor)	1.02×10^5	1.66×10^4	83.7	[1]
	Walls					1.02×10^4	0.09×10^4	91.2	
	Feed trough					3.47×10^3	1.35×10^3	61.1	
	Water pipes					4.36×10^5	2.45×10^4	94.4	
	Cage floor					8.51×10^3	6.92×10^3	18.7	
Swine house	Floor	Culturable bacteria	6.3–6.5	300	Flushing	7.08×10^7	6.03×10^6	91.5	[2]
	Walls					1.51×10^4	< 10	> 99.9	
	Rails					7.94×10^5	6.46×10^4	91.9	
Laying hen house	Floor	Culturable bacteria	5.7–5.8	60–100	Spraying (110 mL·m^{-2} floor)	4.27×10^5	$(1.48-0.85) \times 10^5$	65.3–80.1	
		Coliforms				3.31×10^4	$(1.91-1.07) \times 10^4$	42.3–67.7	[3]
		Staphylococci				4.57×10^4	$(1.91-1.35) \times 10^4$	58.2–70.5	
		Yeasts and molds				2.45×10^4	$(0.91-0.55) \times 10^4$	62.9–77.6	
	Walls	Culturable bacteria	5.7–5.8	60–100	Spraying (110 mL·m^{-2}floor)	3.98×10^3	$(0.79-0.24) \times 10^3$	80.2–94.0	
		Coliforms				371.5	79.4–14.5	78.6–96.1	
		Staphylococci				257.0	70.8–19.1	72.5–92.6	
		Yeasts and molds				199.5	18.2–15.8	90.9–92.1	
	Feed trough	Culturable bacteria	5.7–5.8	60–100	Spraying (110 mL·m^{-2} floor)	1.70×10^3	$(0.19-0.07) \times 10^3$	88.8–95.9	
		Coliforms				426.6	29.5–2.4	93.1–99.4	
		Staphylococci				17.4	4.6–1.3	73.6–92.5	
		Yeasts and molds				199.5	33.9–25.1	83.0–87.4	
	Egg conveyor	Culturable bacteria	5.7–5.8	60–100	Spraying (110 mL·m^{-2} floor)	3.54×10^5	$(1.20-0.62) \times 10^5$	66.1–82.5	
		Coliforms				3.39×10^4	$(0.93-0.50) \times 10^4$	72.6–85.3	
		Staphylococci				3.24×10^4	$(0.85-0.69) \times 10^4$	73.8–78.7	
		Yeasts and molds				3.09×10^3	$(1.02-0.49) \times 10^3$	67.0–84.1	

Note: SAEW, slightly acidic electrolyzed water; ACC, available chlorine concentration.

Table 3 Reduction in airborne microbial by spraying SAEW in animal houses

Indoor air	Microbes	pH	ACC/($mg \cdot L^{-1}$)	Treatment	Spraying method/Starting time	Microbial Concentration/($CFU \cdot m^{-3}$)		Ratio[2]	Reference
						Before	After[1]		
Laying hen house	Culturable bacteria	–	–	no spraying (Control)	–	1.55×10^3	6.61×10^3	4.26	[15]
		5.8–6.2	156	spraying (120 $mL \cdot m^{-2}$ floor)	high-pressure nozzle sprayer (manual spraying)/11:00 a.m.	1.66×10^3	3.47×10^3	2.09	
		5.8–6.2	202	spraying (120 $mL \cdot m^{-2}$ floor)		1.48×10^3	1.26×10^3	0.85	
		5.8–6.2	262	spraying (120 $mL \cdot m^{-2}$ floor)		2.45×10^3	0.41×10^3	0.17	
		5.8–6.2	262	spraying (90 $mL \cdot m^{-2}$ floor)		2.09×10^3	3.63×10^3	1.74	
Layer breeding house	Culturable bacteria	–	–	no spraying (Control)	–	1.82×10^5	1.90×10^5	1.04	[54]
		5.3–6.3	250	cleaning + spraying (120 $mL \cdot m^{-2}$ floor)	high-pressure nozzle sprayer (manual spraying)/11:00 a.m.	1.57×10^5	0.95×10^5	0.61	
	Fungi	–	–	no spraying (Control)	–	5.67×10^3	6.13×10^3	1.08	
		5.3–6.3	250	cleaning + spraying (120 $mL \cdot m^{-2}$ floor)	high-pressure nozzle sprayer (manual spraying)/11:00 a.m.	7.28×10^3	5.01×10^3	0.69	
Aviary laying hen chamber	Culturable bacteria	–	–	no spraying (Control)	–	2.31×10^5	4.72×10^5	2.12	[33]
		–	–	spraying water (80 $mL \cdot m^{-2}$ floor)	high air pressure spray gun (manual spraying)/14:00 p.m.	2.04×10^5	4.01×10^5	1.97	
		6.0	80	spraying (80 $mL \cdot m^{-2}$ floor)		2.74×10^5	2.25×10^5	0.92	

Note: SAEW, slightly acidic electrolyzed water. [1], microbial sampling was conducted about 30 min after spraying SAEW; [2], airborne microbial concentration ratio comparing post- to pre- treatment.

the size of sprayed aerosols and the ventilation can influence the inactivation efficiency of spraying SAEW or NEW on airborne microbes. Chuang et al.[75] evaluated the inactivation efficiency of spraying NEW on *E. coli* and *B. subtilis* bacterial aerosols in a controlled environment chamber. The results indicated that spraying NEW is likely to be effective in inactivation of airborne bacterial contamination. Moreover, an increase in ventilation rate (air exchange rate 0.5–1.0 per hour) and increase in aerosol count median diameter of sprayed aerosols (0.12–0.2 µm) may facilitate the inactivation efficiency. Available chlorine loss caused by spraying is greatly dependent on the size of sprayed aerosols. The size of sprayed aerosols can also influence the gas-liquid contact, which is important for the probability of exposure of airborne microbes to sprayed SAEW or NEW aerosols. Smaller sprayed aerosols may promote the gas-liquid contact but cause greater loss of available chlorine during spraying. Zhao et al.[79] reported an initial available chlorine loss of 11.7%–13.2% when spraying SAEW with an aerosol count median diameter of 80 µm. Our recent study evaluated the reduction efficiency of airborne culturable bacteria by spraying SAEW with different aerosol count median diameters in a controlled environment chamber. Spraying with medium size aerosols (count median diameter = 60–90 µm) is recommended for disinfection in animal houses. Spraying SAEW was also reported to be useful for scrubbing air exhausted from a poultry house by reducing ammonia and culturable bacteria[35,103].

Spraying SAEW or NEW can destroy the microorganisms and slow their growth by direct contact with the microorganisms. However, the effect will reduce and vanish over time after spraying and the microbial populations both on the surfaces and in the air will increase again. Spraying SAEW can slow the increase of the microbial population in the air after spraying[15]. The remaining period for the effect of spraying SAEW or NEW has not been elucidated in current studies. It can be influenced by many factors such as ACC, spraying volume, size of sprayed aerosols, initial airborne microbial population, ventilation and management practices after spraying. Additionally, the surface and air disinfection in animal houses can have interactions. Microorganisms attached to the surfaces in animal houses can go into suspension in the air when they are disturbed by air-flow or animal activity. Also, airborne microorganisms can be attached to the surfaces from the air due to a series of processes such as gravitational sedimentation, impaction and electrostatic precipitation. Surface disinfection contributes to reducing the suspended microorganisms in the air after spraying. Also, air disinfection can lower the microbial population on the surfaces after spraying.

In summary, a large number of studies have revealed SAEW to be novel disinfection agents for both surface disinfection and air disinfection in animal houses. They represent alternative disinfection agents which are highly effective, healthy and environmentally friendly for the application in animal houses. AEW is not applied for disinfection in animal houses, due to its strong acidity which can cause severe corrosion and rapid Cl_2 volatilization. More available chlorine exists as HOCl in SAEW compared to NEW, which means that SAEW will be more effective than NEW at the same ACC. This may explain why SAEW is more often employed for disinfection in animal houses than NEW. It is suggested that using SAEW with high ACC is best for reducing microbial populations in animal houses, due to their high level of organic matter. The system generating SAEW by electrolyzing dilute NaCl and HCl solutions in a non-membrane electrolytic cell is usually employed to produce SAEW for application in animal houses. This system not only produces SAEW with high ACC but also avoids the use of membranes in the electrolysis cell. Spraying SAEW is extensively applied for disinfection in animal houses, including surface and air disinfection. Spraying SAEW showed high antimicrobial activity on surfaces in animal houses and increasing the ACC of SAEW and the spraying volume can improve the antimicrobial effectiveness on these surfaces. Airborne microbial populations in animal houses can also be greatly reduced by spraying SAEW. The antimicrobial activity is influenced by ACC, spraying volume, size of sprayed aerosols, and ventilation of the building. Spraying SAEW can lower the microbial populations in animal houses, preventing animals and workers being exposed to high levels of pathogens.

6 Conclusions

EW exhibits strong antimicrobial activity against a broad spectrum of microorganisms. The definitions of SAEW and NEW are clarified in this review. SAEW and NEW can be produced by different systems, affecting their active components and thereby their antimicrobial activity. HOCl and OCl^- are responsible for the antimicrobial activity of SAEW and NEW. Spraying SAEW is considered as an alternative approach for reducing the microbial populations in animal houses. Increasing the ACC of SAEW and the spraying volume could improve its antimicrobial effectiveness on the surfaces in animal houses. The airborne microbial population in animal houses can be greatly reduced by spraying SAEW. The airborne microbe reduction by spraying SAEW is influenced by ACC, spray volume, aerosols size and ventilation.

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Li declare that they have no conflicts of interest or financial conflicts to disclose.

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