

## Stability of electrolyzed water: from the perspective of food industry

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### Article history:

Received: 18 April 2020

Received in revised form: 23

July 2020

Accepted: 11 October 2020

Available Online: 3 January 2021

### Keywords:

Disinfection,

Electrochemically activated water,

Electrolysis,

Novel disinfectants,

Sanitation,

Sustainable cleaning

### Abstract

Green cleaner and disinfectant can provide a better environment and they can reduce cleaning cost by eliminating the cost of harsh cleaning chemicals, minimizing cleaning chemicals storage space, reducing cost for wastewater treatment and reducing logistics cost for chemical supply. This study explored the personal view of Small and Medium Enterprises (SMEs) top to bottom workers towards the challenges during cleaning and disinfection process and their readiness in accepting a green cleaner and disinfectant. In this work, the advantages and disadvantages of electrolyzed water (EW) as green cleaner and disinfectant were discussed. A lab-scale batch ion-exchange membrane electrolysis unit was used to produce acidic electrolyzed water (AcEW) and alkaline electrolyzed water (AIEW). The stability of AcEW and AIEW was also studied based on its physical changes (pH, oxidative-reduction potential (ORP), chlorine content and hydrogen peroxide content) in 7 days of storage, whereby measurements were taken daily. The pH maintained for both AcEW and AIEW during the 7 days of storage. The ORP maintained at plateau for the first 5 days of AcEW storage. After 5 days, AcEW showed a decreasing trend. While ORP for AIEW increases drastically between day 1 and 2. Then, the ORP reaches a plateau after three days. The amount of free chlorine, total chlorine and hydrogen peroxide content was 10 mg/L, respectively, on the day of production. However, all the properties decreased gradually and there were no chlorine and hydrogen peroxide detected on the 7th day. The results from this study can be used as a guideline to store the EW and to understand the stability of the EW, which can benefit the SME food manufacturers.

### DOI:

[https://doi.org/10.26656/fr.2017.5\(S1\).027](https://doi.org/10.26656/fr.2017.5(S1).027)

## 1. Introduction

Selection of suitable cleaning detergents and disinfection (or also known as sanitisation in the USA) for SMEs can be costly and complex. Considering SMEs financial aspect, they are facing difficulties in finding a balance between the cleaning detergent cost and its performance. Food-grade cleaning detergents are easy to rinse and poses less harm to food contact surfaces and food products. However, these types of detergents can be expensive and can be a burden to SME food manufacturers. Generally, there are three types of cleaning detergents for the food industry: 1) pure

chemicals, 2) formulated detergents and 3) pure chemicals with additives. The main components of all chemicals are always an alkali or an acid. The selection of the main components is depending on the nature of food soil in the processing system. Then, after the cleaning process, the food contact surfaces are disinfected to inactivate microorganism that is harmful to humans. Disinfection of food contact surfaces can be done with moist heat at a range of 90 to 95°C (Tetra Pak International S.A., 2015), with hot water of 75°C (Heinz and Hautzinger, 2007; Watkinson, 2008; Hui, 2012; Khalid *et al.*, 2019) or with chemicals (Khalid *et al.*, 2016). Food manufacturers commonly use two types of

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cleaning detergents in order to achieve cleanliness. Sodium hydroxide is commonly used as an alkaline-based detergent to remove the carbohydrate-based fouling deposit for cleaning, and disinfectant (e.g., sodium hypochlorite) is used for disinfection (Walton, 2008). Alkaline-based cleaning chemical is commonly used for cleaning food-contact surfaces. Acid cleaning cycle (e.g., acetic acid) is added onto food contact surfaces that process food (commonly dairy products) that contain mineral such as calcium, phosphorous, and riboflavin (Walton, 2008).

Even though there are formulated cleaning detergents which can cater function of multiple cleaning and disinfection chemicals, there is still a need to find a green cleaner as we are becoming increasingly health and eco-conscious. Thus, the demand for sustainable initiatives also grows. One of the green cleaner available today is the electrolyzed water (EW). EW is one of the green alternatives solution for both cleaning and disinfection chemicals whereby EW can be produced through the electrolysis process of salt solution only. As the electrolysis cell with an ion-selective membrane is subjected to current, two types of solution are produced. Acidic electrolyzed water (AcEW) is produced at anode. AcEW contains hydrogen peroxide,  $H_2O_2$  (Rico et al., 2007; Stanga, 2010), ozone gas,  $O_3$  (Guzel-Seydim et al., 2004; Stanga, 2010; Meireles et al., 2016), hypochlorous acid, HOCl, hypochloric acid, HCl (Meireles et al., 2016) and hypochlorite ion,  $ClO^-$  (Meireles et al., 2016). All of these components make AcEW to be a powerful sanitiser in disinfecting many types of foodborne pathogens such as *Salmonella* (Venkitanarayanan et al., 1999; Fabrizio and Cutter, 2004), *Escherichia coli* (Venkitanarayanan et al., 1999; Ozer and Demirci, 2006) and *Listeria monocytogenes* (Venkitanarayanan et al., 1999; Ozer and Demirci, 2006). Whereas alkaline electrolyzed water (AIEW) contains sodium hydroxide; a grease-cutting cleaner produced at cathode. In contact with NaOH, fouling deposit will swell and assist the dirt removal (Khalid et al., 2016).

Most of the SME factories have small factory areas which allow them to have limited storage area. Bulk purchasing of cleaning detergents can reduce the total cleaning cost, but the limited storage area becomes a hindrance. Moreover, SMEs only use a small amount of cleaning detergents which leads to more cleaning detergents becoming expired. Treatment or disposal of the expired chemicals will only contribute to a negative effect on the environment and increase the operating cost. EW is seen as a potential in solving the storage problem as it can be produced on-site and does not need any storage area (Khalid, Ab Aziz, Thani et al., 2020).

The research is aimed to identify the potential of EW as green cleaner and disinfectant in the food industry SMEs. The effect of storage duration on chemical properties of acidic electrolyzed water (AcEW) and alkaline electrolyzed water (AIEW) was also studied. The results obtained from this work can be used as a guideline for SMEs to apply and store the EW reasonably.

## 2. Materials and methods

### 2.1 Identifying the potential of EW as green cleaner in the food industry

Face to face unconstructed interviews (impromptu) were conducted in an SME meat processing factory (factory X) in Selangor, Malaysia. The factory produced different types of burgers (beef, lamb and chicken). The manufacturing process of the factory includes weighing, flaking, mincing, pre-mixing, mixing, burger forming, blast freezing, packing and frozen storage (Khalid, Saulaiman, Nasiruddin et al., 2019). Questions related to cleaning and sanitation process were asked during the interviews. The interview was not transcribed. However, notes were taken during the interview. The purpose of this interview is to understand the difficulties of SME food manufacturer in implementing good cleaning practices. The questions included the selection of cleaning and disinfection detergents, storage for cleaning apparatus and chemical storage conditions. A short visit during cleaning was also conducted. Moreover, the potential application of EW in the food industry for replacing commercial cleaning chemicals was also asked during the interview. Several workers related to cleaning and sanitation process were interviewed with 1) production manager, 2) quality assurance/quality control (QA/QC) manager, 3) production worker 1, and 4) production worker 2.

### 2.2 Preparation of electrolyzed water

A laboratory-scale batch electrolysis unit was used to generate acidic electrolyzed water (AcEW) and alkaline electrolyzed water (AIEW). The electrolysis unit (Figure 1) was designed and constructed at the Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia. Both the cathode and anode chambers were made of acrylic glass that allowed visual observation during the electrolysis process. The chamber can be filled with electrolyte up to 6 litres (3 litres per chamber). The chambers are separated by a polyester UF membrane which allowed ion exchange during the electrolysis process. DC power supply (PSW, 0 – 30 V, 0 – 36 A, GW Instek, Taiwan) is used to control the voltage. In this work, 3.4 L diluted sodium chloride solution (R&M Chemicals, United

Kingdom) was poured into the electrolysis unit (1.7 L salt solution in each chamber). Both the cathode and anode which were made of stainless steel 316 were installed and the chamber was closed. Then, current approximately in the range of 2.0 to 2.2 A was subjected to the electrolysis unit. At the end of the electrolysis process, AcEW and AIEW were collected at anode and cathode chambers, respectively.

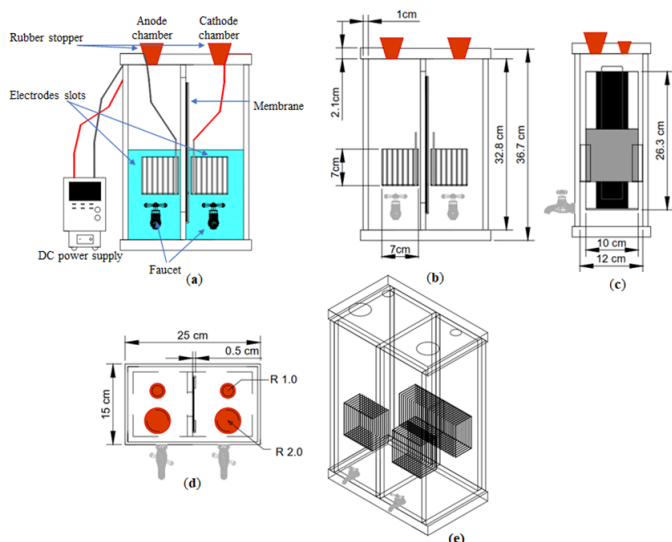


Figure 1. Schematic diagram of the laboratory-scale batch electrolysis unit: a) front-side view (complete set-up), b) front-side view c) right view, d) top-side view and e) perspective view.

### 2.3 Stability of electrolyzed water

After electrolysis, the changes towards the chemical properties (pH, oxidation-reduction potential (ORP), free chlorine, total chlorine and hydrogen peroxide content) of EW were tested. Then, 100 mL of AcEW and 100 mL of AIEW were stored in a dark brown tightly-screwed closed bottle at room temperature (25-30°C). The amount of pH, ORP, free chlorine, total chlorine and hydrogen peroxide content of EW were measured at every 24 hrs for 7 days according to previous researchers (Hsu and Kao, 2004; Cui, et al., 2009; Khalid et al., 2018). For every 24 hrs, the bottles were opened for approximately 5 mins for analytical measurements. The experiment was repeated for 3 times and each repetition was carried out at different week.

### 2.4 Analytical measurement of electrolyzed water

Free and total chlorine test strips 0 – 10 mg/L (Hach, Unites State) were used to estimate the free chlorine and total chlorine content in electrolyzed water. The hydrogen peroxide test strip 0 – 10 mg/L (Macherey-Nagel, Germany) was used to estimate the content of hydrogen peroxide. The pH was measured using a portable pH/mV/ISE meter equipped with pH electrode (Fisher Scientific, USA). Oxidation-reduction potential (ORP) was measured using a portable pH/mV/ISE meter equipped with redox electrode (Boeco, Germany). Table 1 shows the reactions involved during the electrolysis process (Al-Haq et al., 2005; Rahman et al., 2016). As shown in Table 1, chlorine and hydrogen peroxide are only generated at the anode chamber which contributes to the AcEW's properties. Thus, the pH, ORP, free chlorine, total chlorine and hydrogen peroxide are measured for AcEW. Whereas, only pH and ORP were measured for the AIEW.

## 3. Results and discussion

### 3.1 Background of the impromptu interview

Factory x, a meat processing factory was used in this work. Factory x was chosen as the case study due to the prior research conducted by (Hasnan et al., 2019). Hasnan et al. (2019) proposed a spine plant layout design for the factory x. The suggested spine plant layout that was proposed by Hasnan et al., (2019) was expected to improve the food hygiene and reduce the travelled distances inside this small-scale meat processing factory. After the implementation of the new plant layout, a short visit was conducted. The improved plant layout itself solely cannot improve the hygienic environment of the factory. Thus, during the visit's meeting, the topic regarding improving the cleaning and sanitation of factory x was discussed. The group meeting was attended by the production manager and the QA/QC manager. They explained the cleaning and sanitation difficulties that they were facing. The meeting took about one and a half hours. Notes were taken during the meeting. After the meeting, two production workers were interviewed individually. The individual interview took about 30 mins each. During the interview and discussion, notes were taken. The finding was determined based on the notes taken and the observation

Table 1. Reactions involve during the electrolysis process (Al-Haq et al., 2005; Rahman et al., 2016)

Anode	Cathode
$2\text{NaCl} = \text{Cl}_2 (\text{g}) + 2\text{e}^- + 2\text{Na}^+$	$2 \text{H}_2\text{O}_2 (\text{l}) + 2\text{e}^- = 2\text{OH}^- + \text{H}_2 (\text{g})$
$2\text{H}_2\text{O}(\text{l}) = 4\text{H}^+ (\text{aq}) + \text{O}_2 (\text{g}) + 4\text{e}^-$	$2\text{NaCl} + 2\text{OH}^- = 2\text{NaOH} + \text{Cl}^-$
$\text{Cl}_2 + \text{H}_2\text{O} (\text{l}) = \text{HCl} + \text{HOCl}$	
$\text{H}_2\text{O} = \text{H}^+ + \cdot\text{OH} + \text{e}^-$	
$\cdot\text{OH} + \cdot\text{OH} = \text{H}_2\text{O}_2$	
<ul style="list-style-type: none"> <li>• Acidic electrolyzed water is obtained</li> <li>• Chlorine species (HCl, HOCl) are generated</li> <li>• Hydrogen peroxide is generated (<math>\text{H}_2\text{O}_2</math>)</li> </ul>	<ul style="list-style-type: none"> <li>• Alkaline electrolyzed water is obtained</li> <li>• Sodium hydroxide (NaOH) is generated</li> </ul>

during the visit. The themes and similarity of the notes were analysed.

### 3.2 Challenges of cleaning from Small and Medium Enterprise (SME) perspectives

Based on the group discussion (meeting) and individual reflection of production workers, four major problems were identified which are: 1) difficulty in selecting the cleaning and disinfection chemical, 2) limited knowledge in cleaning and disinfection process, 3) budget constraints and 4) limited storage area. First, in implementing a cleaning program, the selection of good cleaning detergents is very difficult for SMEs. They claim that food-grade detergents are expensive and eventually can become a burden. Thus, they tend to purchase a cheap cleaning detergent without any proper material safety data sheet (MSDS).

Second, they believe visual cleanliness is the only indicator which can validate their cleaning programs. Most of the SMEs are unaware of cleaning indicators for food industries which are physical (visual, touch and smell), microbiological and chemical cleanliness (Khalid et al., 2019). These indicators are also known as cleaning target for some food industries. These three cleanliness indicators are important to ensure the products are safe and do not contaminate microbiologically, physically and chemically (Walton, 2008). Moreover, a clean environment contributes to a more healthy and safe working environment for workers. Maintaining cleanliness in food manufacturing premise is of the utmost importance to create a safe, enjoyable, comfortable, and stress-free environment for workers in the food industry (Khalid et al., 2019).

Third, food SMEs have a limited budget which constraints them in implementing a good cleaning process. They tend to skip the costly cleaning process such as hot water rinsing. Hot water rinsing is used to melt the invisible fat layer which is commonly found in meat processing area (Khalid and Ab Aziz, 2019). SMEs try to avoid boiler utilization as it will increase the operating and maintenance cost (Khalid and Ab Aziz, 2019). This hot water rinsing increases the cleaning performance and also capable to act as disinfectant in inactivating foodborne pathogens (Heinz and Hautzinger, 2007; Watkinson, 2008; Hui, 2012; Khalid et al., 2019). An expensive disinfectant chemical can be replaced with this hot water rinsing process at 75°C (Heinz and Hautzinger, 2007; Watkinson, 2008; Hui, 2012; Khalid et al., 2019). This will reduce the operating cost. However, most of food SMEs do not know about this and continue to purchase expensive disinfectant chemicals. Then, when they were asked if they are willing to accept other cleaning chemical solution, they

stated that they are open for the suggestion as long as the alternative cleaning solution is cheap and effective. Thus, EW, which is environmentally friendly and cheap can be accepted in SME factories.

Last but not least is the limited storage area. Bulk purchasing of cleaning chemicals can reduce the total cleaning chemicals cost. However, the storage area of SMEs is quite small. Most of the SME factories were set-up in a small and limited factories area. Thus, they have small chemical storage area which they have to store all unused (unopened bottles) chemicals, used chemicals, expired chemicals and cleaning apparatus (brushes, sweep, sponge etc.). Disposal of expired chemicals can be costly. Thus, they eventually decided to store the expired cleaning chemicals. EW which can be generated on-site does not need big space for storage and does not require further wastewater treatment. These are the key criteria which enhance the acceptance of EW in SME for cleaning and sanitation.

### 3.3 Electrolyzed water as an affordable and green cleaner

Electrolyzed water is claimable as a green and cheap cleaner with high potential as detergents for both cleaning and disinfection (Al-Haq et al., 2005; Rahman et al., 2016). Based on the interviews with SMEs, they are willing to accept this technology as the cost using EW is low because the only operating expenses are water, salts, and electricity in order to run the electrolyzing unit (Al-Haq et al., 2005; Rahman et al., 2016). However, the cost for initial capital investment to purchase the EW generator is not considered when calculating the cost. To date, there is no report made on the cost advantages regarding the usage of electrolyzed water in food industries. The actual cost advantage needs to be determined (Dev et al., 2014). The actual cost should consider the price of the initial purchase of EW generator, the shelf life of the EW generator, shelf life of electrode's materials (material for cathode and anode for electrolysis) and the membrane's shelf life. There are two main corrosive components in electrolyzed water which are salt and chlorine (Khalid, Sulaiman, Ab Aziz et al., 2020). Corrosion will reduce the electrode's material performance by reducing the current flow (Hsu et al., 2015, Khalid, Sulaiman, Ab Aziz et al., 2020). Eventually, the brown precipitate formed due to corrosion can attach to the membrane and eventually limiting the ion-exchange process (Khalid, Sulaiman, Ab Aziz et al., 2020). Frequent replacement of electrodes and membrane is needed. Therefore, future analysis may include short- and long-term cost analyses.

Alkaline electrolyzed water (AIEW) contains sodium hydroxide (Table 1); a grease-cutting cleaner which is

able to remove oil, grease and fat. Detergency test using AIEW shows that it is able to eliminate 100% of the animal and vegetable oil formed on the steel's surface effectively (Shirota and Isaka, 2001). Since the properties of the AIEW are not affected by the heat effect, cleaning using AIEW at a higher temperature will contribute to higher cleaning efficiency (Dev et al., 2014). AIEW is also able to remove protein-based soil. For milking system that used cleaning-in-place (CIP) program for cleaning, AIEW has proven its potential to replace the sodium hydroxide (NaOH) (Dev et al., 2014; Wang et al., 2016). Whereas, acidic electrolysed water (AcEW) can be used to replace acidic-based detergent (Dev et al., 2014; Wang et al., 2016). Dev et al. (2014) and Wang et al. (2016) applied AcEW during cleaning-in-place (CIP) process to clean the milking system as fouling deposit consists of some minerals. Their experimental works show that AcEW can replace the acid-based detergent and the sanitiser for CIP process of the milking system.

### 3.4 Electrolyzed water as environmentally friendly cleaning medium

Utilizing EW during cleaning is better for the environment, worker's safety and food safety as EW is less toxic than petroleum-based cleaning chemical (Colangelo et al., 2015; Gil et al., 2015; Rood et al., 2018). Food manufacturer acceptance of EW as cleaning medium, however, will likely depend on how well they can overcome the stigma that EW can cause equipment surface corrosion. Cleaning food equipment directly with salt solution can damage and reduce the shelf life of the equipment. This is one of the worries raised from SMEs when EW was suggested as an alternative green cleaner (Khalid, Ab Aziz, Thani et al., 2020). However, Ayebah and Hung (2005) reported that EW is less corrosive to stainless steel. Carbon steel, copper, aluminium and stainless steel had a fair, good and outstanding corrosion resistance in EW, respectively. Ayebah and Hung (2005) also indicated that AcEW water did not have any adverse effect on stainless steel. Stainless steel is the safest and suitable material for food contact surface manufacturing. Stainless steel shows an outstanding corrosion resistance in EW (Khalid, Sulaiman, Ab Aziz et al., 2020). Rinsing is a very important step in protecting the shelf life of the equipment material to avoid corrosion and to remove the chemical residue. After disinfection, washing the food equipment with sterile water can completely avoid metal corrosion (Ayebah and Hung, 2005). The effectiveness of rinsing can be measured by monitoring the conductivity (Stanga 2010). Conductivity is a measure of the concentration of the dissolved mineral in water (Etienne, 2006; Stanga, 2010). Moreover, EW reverts back to the original state when in contact with organic

matter or if it is diluted by tap water, osmosis water or distilled water (Hati et al., 2012), thus reducing cost for wastewater treatment.

### 3.5 Storage of acidic electrolyzed water

Figure 2 shows properties (pH, ORP, free chlorine, total chlorine and hydrogen peroxide) of AcEW during the 7 days of storage. There were two main factors which can reduce the chemical properties of EW which are exposed to the atmosphere and long duration of storage (Hsu and Kao, 2004; Khalid et al., 2018). In this work, seven days of storage was set as storage time assuming the food industries generate EW (using an EW generator) once a week for weekly consumption. From the SMEs perspective, daily usage of EW generator might be costly as it requires electrical energy to operate. Moreover, the weekly operation of the EW generator will be more convenient for the workers. Moreover, the common design of EW generator has a storage tank for EW. During the sanitation process, the tank is used to maintain a high flow rate of EW supply. Therefore, it is important to determine the EW stability (AcEW and AIEW) during storage. As shown in Figure 2 (a), the pH of AcEW remained stable during the seven days of storage. Maintaining the acidic pH is very important to ensure that the AcEW can be used as acidic cycle chemicals. Acidic chemicals such as acetic acid and phosphoric acid are commonly used for dairy cleaning (Watkinson, 2008). Acids are generally used to remove mineral scales such as hard water and millstones scales. While the ORP as shown in Figure 2 (b) maintains at a plateau for the first 5 days of storage. After 5 days, the AcEW shows a decreasing profile. Both pH and ORP are important properties to maintain as these properties contribute to AcEW antimicrobial properties. The high ORP (Kim et al., 2000; Liao et al., 2007; Huang et al., 2008), low pH (McPherson, 1993; Huang et al., 2008), chlorine content (Park et al., 2004; Liu, Duan and Su, 2006; Huang et al., 2008) and hydrogen peroxide content (Rico et al., 2007) are important chemical characteristics that contribute to antimicrobial properties of AcEW. Since aerobic and anaerobic bacteria can grow optimally at an ORP range of +200 to 800 mV and -700 to +200 mV, respectively. Thus, our target is to maintain our AcEW more than 800 mV. At higher ORP, the metabolic fluxes and ATP production of bacteria are modified (Huang et al., 2008). The pH ranging from 4 to 9 is optimal growth for bacteria. Our target is to maintain our AcEW to be lower than the pH of 4.

During the 4 days of storage, the free and total chlorine content maintained at 10 mg/L (Figure 2 (c) and Figure (d) respectively). After 4 days, the total and free chlorine were found to be reduced gradually. However,

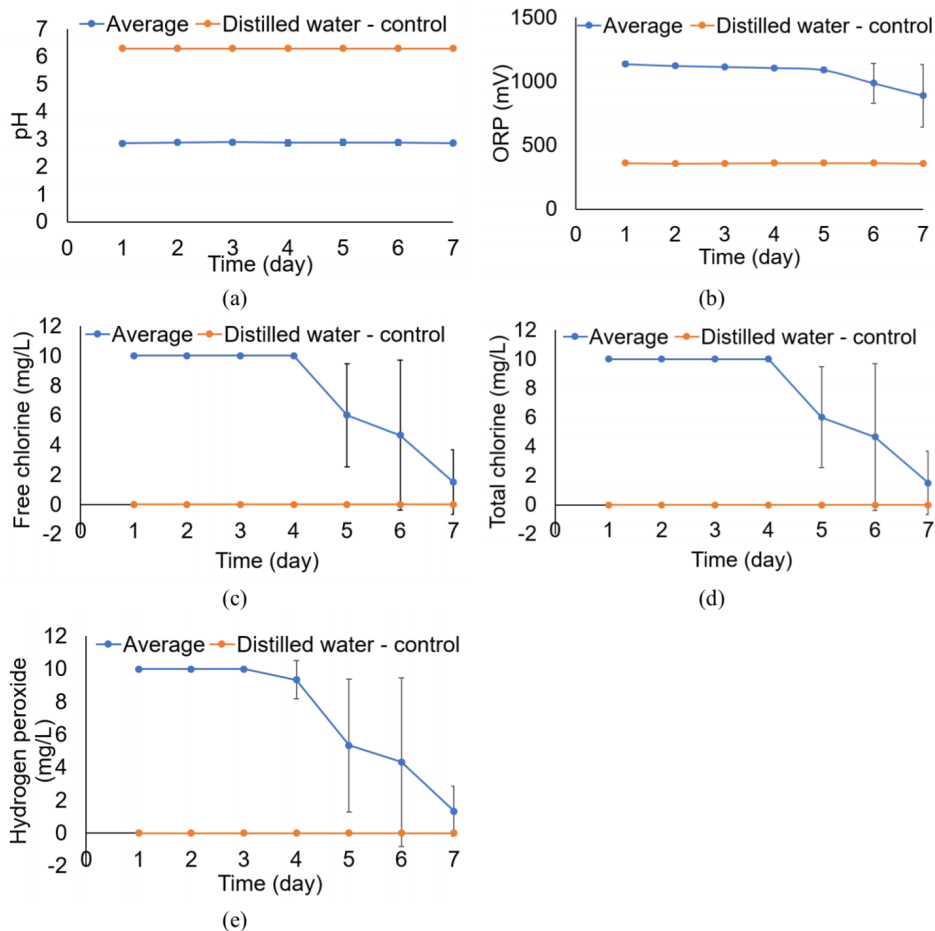


Figure 2. Effect of storage on the chemical and physical properties of the AcEW: a) pH, b) ORP, c) free chlorine, d) total chlorine and e) hydrogen peroxide.

the reduction rate was inconsistent for each repetition (large error bar). Large error bar indicates the large standard deviation. This might happen because the exposure to the atmosphere during daily measurement might reduce the total and free chlorine content. Every day, the bottle was opened for approximately 5 mins for physical properties measurements. When measurement time took less than 5 mins, the bottles were closed immediately. However, if the measurement time was delayed, the time the AcEW bottles were opened can be more than 5 mins. This mostly happens because the ORP meter takes some time to reach its accurate values. Thus, the exposure to the atmosphere might reduce the chlorine content inside AcEW. On day 7, there was almost no chlorine available in the AcEW. At lower pH of 2.3 to 2.7, the outer membrane of bacteria will break down, allowing hypochlorous acid (HOCl) to enter the inner membrane of the bacteria (Huang *et al.*, 2008). HOCl is one of the most active compounds in chlorine compound. HOCl is highly oxidative and can deactivate the foodborne pathogens. HOCl reacts with DNA, induces the DNA-protein interactions, produces pyrimidine oxidation products and adds chloride to DNA bases (Birben *et al.*, 2012). Thus, it is very important to maintain the chlorine content in AcEW.

Figure 2 (e) shows the properties of hydrogen peroxide during the 7 days of storage. The decrement pattern for  $H_2O_2$  properties is similar to free and total chlorine (Figure 2 (c) and Figure 2 (d) respectively). The  $H_2O_2$  maintained at 10 mg/L until day 3 and after that, the  $H_2O_2$  level decreased drastically. On day 7, there were 0, 4 and 1 mg/L  $H_2O_2$  (1st, 2nd and 3rd repetition, respectively) that were detected in AcEW. Thus, it is very important to minimize the opening time of the bottles during storage. These results have proven that AcEW can be used as a good cleaner (acidic cycle chemicals) and disinfectant chemical as well. Hydrogen peroxide ( $H_2O_2$ ) has a strong detaching ability and kills bacteria without causing corrosion (Stanga, 2010).  $H_2O_2$  also does not generate off-odours typical chlorine derivatives such as chlorophenols and chloramines (Stanga, 2010). None of the prior studies has reported the effect of  $H_2O_2$  content in AcEW. The small size of  $H_2O_2$  enables it to clean the membrane effectively as it can pass through small filtration membranes and enhances the biofilm removal and disinfection process (Stanga, 2010). By considering the pH, ORP, chlorine content and hydrogen peroxide content, the AcEW was at its best performance for 3 days.

### 3.6 Storage of alkaline electrolyzed water

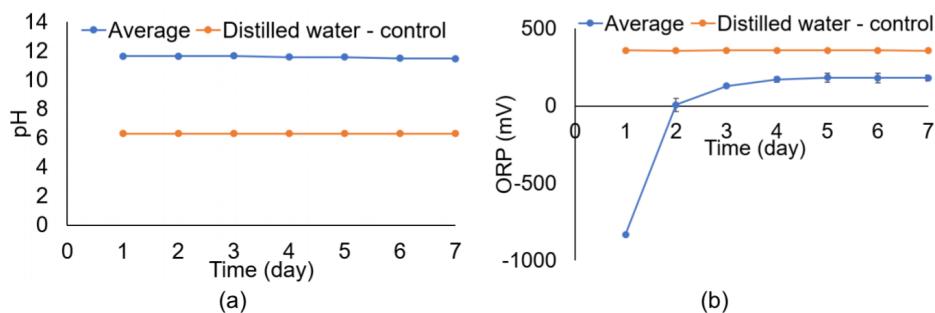


Figure 3. Effect of storage on the chemical and physical properties of a) pH and b) ORP of the AIEW.

Figure 3 shows the properties (pH, ORP) of AIEW during the 7 days of storage. Studies on storage of AIEW have not been well conducted as compared to AcEW (; Hsu and Kao, 2004; Ciu *et al.*, 2009; Hsu *et al.*, 2015) as most literature were focusing on the chlorine changes after storage time. Storage might affect the cleaning or removal performance of AIEW. The AIEW contains NaOH which is one of the detergent components used widely for cleaning food equipment surfaces (Walton, 2008; Khalid *et al.*, 2016). The AIEW has the ability to act as NaOH and functions well in cleaning food processing equipment (Wang *et al.*, 2016). The AIEW has been used to replace the alkaline wash in works by Dev *et al.* (2014) and Wang *et al.* (2016). AIEW has shown to give the same effect as NaOH during the alkaline wash. Alkaline detergent is good in removing organic soil (fat, protein and carbohydrate). When the fouling deposit is in contact with AIEW, the fouling deposit swell. The removal is easier after the swelling stage (Wang *et al.*, 2016). The cohesive strength between the fouling deposits itself will be lesser and the adhesive strength between the surface and fouling deposit reduces (Liu *et al.*, 2006; Law *et al.*, 2009; Ho *et al.*, 2010), thus, enabling the removal of fouling deposit. The alkaline cleaning step is important to ensure the removal of physical deposit. The remaining fouling deposit might act as a barrier and reduce the disinfection agent performance at the later stage of the disinfection process.

Most cleaning chemicals are alkaline in nature. The cleaning removal action (saponification, chelation and dispersion of fouling deposit) occurs effectively at an alkaline pH level. Moreover, alkaline performs best when soil can be hydrolyzed or saponified especially for fat-based fouling deposit such as grease, oils and fats. In this work, the efficiency of AIEW depends on the pH and ORP. Figure 3 shows that the pH of AIEW was stable during 7 days of storage.

Aerobic and anaerobic bacteria can grow optimally at the ORP range of +200 to 800 mV and -700 to +200 mV, respectively. At lower ORP (<-700 mV), the metabolic fluxes and ATP production of bacteria can be modified, which eventually kills the bacteria (Kim *et al.*, 2000; Liao *et al.*, 2007; Huang *et al.*, 2008). Lower ORP

(<-700 mV) is non-ideal for microbes' growth. However, the ORP increased drastically between day 1 and 2. On the first day, the ORP was -829 mV, -831 mV and -837 mV (1st, 2nd and 3rd repetition, respectively). The ORP reduced to 54 mV, -8 mV and -25 mV (1st, 2nd and 3rd repetition, respectively). After that, the ORP of AIEW reached a plateau after day 3. On day 7, the ORP of AIEW were 162 mV, 180 mV and 202 mV (1st, 2nd and 3rd repetition, respectively). Thus, the results have shown that AIEW can be used as alkaline cycle chemicals and disinfectants chemicals. The ORP properties of AIEW are the only antimicrobial properties which reduced drastically during storage. However, since the pH was still high, AIEW can still be effectively used as a disinfection chemical.

#### 4. Conclusion

Green cleaners and disinfection deliver environmental benefits and at the same time can create operational cleaning efficiencies which highly benefit the SMEs manufacturers. This paper aimed to identify the potential of EW as green cleaner and disinfectant in SMEs food industry. Based on the impromptu interview with the workers, SME is facing difficulties to implement good cleaning and sanitation process due to the difficulty in selecting cleaning and disinfection chemical, limited knowledge in cleaning and disinfection process, budget constraints and limited storage area. SME manufacturers are facing difficulties to select suitable cleaning and disinfection detergent which suits them in terms of operational cost and storage area. Previous studies on EW show its potential as a green cleaner as it can be generated on-site, takes up less storage area, cheap and does not require wastewater treatment. In this study, the effect of storage duration on chemical properties of AcEW and AIEW was studied for 7 days. The chemical properties of EW will be reduced as time increased. It is a common practice to use fresh EW immediately after electrolysis to ensure the chemical properties (pH, ORP, free chlorine, total chlorine and hydrogen peroxide content) of EW are at its maximum. However, the common design of EW generator has a storage tank for EW. The tank is used to maintain a high flow rate of EW supply during the sanitation process.

Hence, it is important to identify the stability of AIEW and AcEW during storage. In this work, the AcEW can be stored for 3 days while maintaining all its original properties (pH, ORP, free chlorine, total chlorine and hydrogen peroxide content). AIEW can be stored for 7 days as its pH showed no changes during the 7 days of storage. In order to maintain the physical properties of EW, food manufacturers must tightly close the EW bottles and keep it in a dark bottle to avoid exposure to the atmosphere. The results obtained from this work can be used as a guideline for SMEs to apply and store the EW reasonably. For future work, interviews with several food SMEs companies on the acceptance of EW as sanitation solution alternatives should be done.

### Conflicts of interest

The authors have declared no conflict of interest.

### Acknowledgement

The authors would like to acknowledge the financial support provided by Universiti Putra Malaysia (9548500) Putra IPS grant.

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