Development of device producing electrolyzed water for home care

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Abstract. When water containing ionic substances is electrolyzed, electrolyzed water with strong bactericidal ability due to the available chlorine (AC) is generated on the anode side. Slightly acidic to neutral electrolyzed water (pH 6.5 to 7.5) is physiological pH and is suitable for biological applications. For producing slightly acidic to neutral electrolyzed water simply, a vertical-type electrolytic tank with an asymmetric structure was made. As a result, a small amount of strongly alkaline water was generated in the upper cathodic small chamber, and a large amount of weakly acidic water generated in the lower anodic large chamber. The pH and AC concentration in solution mixed with both electrolyzed water were 6.3 and 39.5 ppm, respectively. This solution was slightly acidic to neutral electrolyzed water and had strong bactericidal activity. This device is useful for producing slightly acidic to neutral electrolyzed water as a disinfectant to employ at home care, when considering economic and environmental factors, since it returns to ordinary water after use.

1. Introduction
Electrolysis is well known as being a method of separating an ionic substance. A device for achieving electrolysis require an electrolyte containing an ionic substance, an anode and a cathode of electrode, a diaphragm and a direct electric current supply. In the electrolysis process, water containing NaCl is electrolyzed with a membrane partition, resulting in the production of strongly acidic electrolyzed water (SAcEW) at the anode and strongly alkaline electrolyzed water (SAIEW) at the cathode (Fig.1). The resulting SAcEW contains an available chlorine (AC) such as hypochlorous acid (HClO), which is known to have a strong bactericidal action, and which thus enables the killing of various microorganisms such as viruses and bacteria[1][2].

Electrolyzed water is classified depending on its pH into SAcEW (pH 2.2 to 2.7), slightly acidic electrolyzed water (pH 5.0 to 6.5), and neutral electrolyzed water (pH 6.5 to 7.5), each having different characteristics. SAcEW shows an instantaneous bactericidal activity, but the activity does not persist. In addition, SAcEW stimulates the oral mucosa etc. because of its strong acidity, and is therefore unsuitable for biological applications. On the other hand, in slightly acidic to neutral electrolyzed water, since the activity persists and its pH is physiological levels, it can be applied to various uses. However, production of slightly acidic to neutral electrolyzed water requires electrolysis of hydrochloric acid itself or use of hydrochloric acid as a pH adjuster. Thus, the production is too complicated to perform in domestic homes or long-term care facilities. Then, in order to obtain slightly acidic to neutral electrolyzed water with the conventional system, an additional process, such
as mixing the two types of electrolyzed water in different amounts, is necessary. Recently we reported that slightly acidic to neutral electrolyzed water can be produced by automatic mixing controller which consists of solenoid valves[3]. However, the conventional generator is unsuitable for exclusively producing slightly acidic to neutral electrolyzed water.

The present study provides a method of directly producing slightly acidic to neutral electrolyzed water showing excellent persistence of the bactericidal effect in a simple and highly efficiently manner with an electrolyzed water generator having a membrane.

![Figure 1. Principle of electrolyzed water production](image)

SAcEW is generated on the anode side and SAI EW is generated on the cathode side.

The chemical reaction is follows,

Anode side

\[
\begin{align*}
H_2O &\rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^- \\
2Cl^- &\rightarrow Cl_2 + 2e^- \\
Cl_2 (aq) + H_2O &\leftrightarrow HClO + HCl
\end{align*}
\]

Cathode side

\[
H_2O + 2 e^- \rightarrow \frac{1}{2}H_2 + OH^-
\]

2. Methods

1) Device

The study provides a vertical-type electrolytic tank with an asymmetric structure having a horizontal membrane, an anode chamber (large chamber) located below the membrane and provided with an anode electrode plate at a position an appropriate distance away from the membrane, and a cathode part (small chamber) disposed above the membrane and provided with a mesh-type cathode electrode plate at a position near the membrane(Fig.2).

Electrolysis is performed by applying a DC 20 voltage between the electrodes in a state in which the anode chamber (large chamber) is filled with saline, but the cathode part (small chamber) contains a small amount of saline, merely immersing the cathode electrode plate therein(Fig.3).

![Figure 2. Design of vertical-type electrolytic tank](image)
2) Measurement

The values of the pH and AC concentration of the electrolyzed water extracted from the second chamber through the pipe were measured, by changing the time during which power was applied to the pair of the cathode and the anode (electrolysis time). The pH and AC concentration of the extracted electrolyzed water were measured at 0, 2, 4, 6, 8 and 10 minutes after the start of the electrolysis.

The measurement of AC concentration in electrolyzed water were measured with diethyl-p-phenylenediamine by a spectrophotometer.

3) Bactericidal activity

Three strains of bacteria (E. coli, S. aureus and B. cereus) were prepared to investigate the bactericidal activity of electrolyzed water after electrolysis for 10 minutes. The bactericidal activity was examined as follows. These three kinds of bacteria were cultivated at 37°C for 24 hours under aerobic-culture in petri dishes. After cultivation, each one colony was incubated with fresh electrolyzed water, also this solutions were added onto the fresh petri dishes and were cultivated for 48 hours. The colony of bacteria in the petri dish was counted and the bactericidal activity was judged.

Results

As a result, a small amount of SAIEW was generated in the upper cathodic small chamber, and a large amount of weakly acidic water generated in the lower anodic large chamber.

A part of this water passed through the mesh-type cathode electrode and the membrane and was mixed with a large amount of weakly acidic water generated in the lower anodic large chamber to produce slightly acidic to neutral bactericidal water in the anodic large chamber.

Though the pH of the solution in the lower tank shifts toward acidic after the start of electrolysis, the solution is mixed with the alkaline electrolyzed water generated in the upper part to become slightly acidic to neutral electrolyzed water 10 minutes later (Table 1).
Table 1. The pH and AC concentration of lower and upper electrolytic tank

| Electrolytic tank lower part | Electrolytic tank upper part |
|-----------------------------|-----------------------------|
| Min | pH of solution | AC concentration (ppm) | pH of solution | AC concentration (ppm) |
|-----|----------------|-------------------------|----------------|-------------------------|
| 0   | 6.7            | 0                       | 6.7            | 0                       |
| 2   | 4.1            | 4.7                     | —              | —                       |
| 4   | 3.9            | 9.8                     | —              | —                       |
| 6   | 3.9            | 15.5                    | 11.4           | 0                       |
| 8   | 3.6            | 29                      | 11.3           | 0                       |
| 10  | 6.7            | 39.5                    | 11.7           | 0                       |

The results of bactericidal activity of electrolyzed water are shown in Table 2. There were many colonies of *E. coli*, *S. aureus* and *B. cereus* in each petri dish as controls. While there were no colony of bacteria in each petri dish after added electrolyzed water.

Table 2. Bactericidal activity of electrolyzed water

| Bacteria | Control (cfu/ml) | SAcEW (cfu/ml) | NEW (cfu/ml) |
|----------|------------------|----------------|-------------|
| *E. coli* | 5.2×10^7         | 0              | 0           |
| *S. aureus* | 3.7×10^7     | 0              | 0           |
| *B. cereus* | 4.8×10^6       | 0              | 0           |

Discussion

Slightly acidic to neutral electrolyzed water has an advantage that its bactericidal activity stably persists for a long time, making it useful for sterilization, killing microorganisms, disinfection, and cleaning, as with strongly acidic electrolyzed water. Though maintenance for membrane replacement is necessary, the present study does not need to discharge water and is therefore highly efficient, without wasting water, and can be suitably applied to intermediate to large systems. In addition, since hydrochloric acid is not used, the electrolyzed water is nontoxic and safe and is also friendly to the environment. Accordingly, it is applicable to electrolyzed water generators producing bactericidal water that can contribute to killing bacteria on equipment and utensils in food factories, sterilization of instruments in medical-related departments, care homes for the elderly, cleaning toilets and the interiors of buildings, and cleaning bathrooms. Furthermore, since bactericidal water can be simply generated and returns to water when discarded, the present study is easy to use for improving public hygiene.

In an electrolyzed water generator having a membrane, equal amounts of acidic water and alkaline water are generated in the respective electrolytic chambers with the same capacities on both sides of the membrane. Consequently, slightly acidic to neutral water cannot be directly produced. A system for mixing appropriate amounts of both types of water generated by electrolysis includes an additional step and is therefore not an efficient method. Alternatively, a system for producing slightly acidic to neutral water by a method using hydrochloric acid as a pH adjuster with a membrane-less system suffers from the problem of handling hydrochloric acid.

The present study is characterized in that the vertical-type electrolytic tank with a horizontal membrane has an asymmetric structure composed of a large anode chamber located below the membrane and a small cathode chamber located above the membrane, and slightly acidic to neutral water with strong bactericidal ability is produced directly in the anode chamber. No agent such as hydrochloric acid is used, and the structure is a simple one that does not need any special tool. In the
structure, a small part of the alkaline electrolyzed water generated in the cathode part (small chamber) remains in the chamber. This is not a problem for repeating electrolysis by extracting the slightly acidic to neutral water from the anode chamber and then feeding saline again. Regarding electrolysis of saline using a membrane, one method uses a two-chamber electrolytic tank where the acidic aqueous solution on the anode side and the alkaline aqueous solution on the cathode side are mixed at an appropriate ratio outside of the electrolytic tank to give electrolyzed water having a pH of 3 to 6. In a three-chamber electrolytic apparatus, acidic electrolyzed water, neutral electrolyzed water, and alkaline electrolyzed water are generated in the respective chambers. However, there has been no report of an apparatus that electrolyzes most of the solution into slightly acidic to neutral bactericidal water in an electrolytic tank having a membrane.

Conclusion
We made a vertical-type electrolytic tank with an asymmetric structure having a horizontal membrane and succeeded to produce lightly acidic to neutral water with strong bactericidal ability is produced directly.

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