Study on Preparation Conditions of Electrolyzed Reduced Alkaline Water

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Abstract. In this study, the preparation conditions (electrolytic voltage, electrode interval and electrolysis time) of electrolyzed reduced alkaline water were optimized. Results show that electrolytic time, electrolytic voltage and electrode interval could influence the water quality of the electrolyzed reduced alkaline water. More electrolysis time, higher of electrolytic voltage, and smaller electrode interval resulted in higher water pH value. More electrolysis time, higher electrolytic voltage, and larger electrode interval resulted in lower water ORP value. The optimum condition for preparation of weak alkaline primary water is 10v electrolytic voltage, 15 mm interval of electrodes and 2 min electrolysis time.

1. Introduction
Safety of drinking water is the basic requirement for a beautiful life. The development of water treatment technology has laid a solid foundation for the drinking water treatment [1]. The drinking water quality played a very positive role in health of humans. With the increasing of complex pollutions were discharged in to environment, conventional drinking water treatment process is difficult to ensure the quality of drinking water, therefore, the problem of drinking water pollution is becoming more and more serious [2]. In order to achieve the goal of safer and better drinking water, some new advanced treatment technologies, such as electrolysis technology, electromagnetic treatment, mineralization and other technologies, have been developed rapidly [3]. The drinking water produced by electrolysis technology is welcomed by consumers was reported to improve human physiological function [4], like eliminate internal redundant free radicals, prevent oxidative damaging [5] and reduce blood cell adhesion and aggregation and remit early coagulation [6].In literatures, this new type of electrolyte drinking water was named as alkaline ion water or weak alkaline ion water [7] [8] [9]. In our study, weakly electrolyzed reduced alkaline water was used according to its characteristics like pH, redox potential and preparation method. The characteristics of this weakly electrolyzed reduced alkaline water were firstly reported by several Japanese scientists in the 1980s. They firstly developed the produce process to quantity produce this weakly electrolyzed reduced alkaline water [10]. Due to water quality and storage problem [11], however, that method did not world widely spread. At present, many devices were invented to produce this water and the household electrolytic water machine is one of the most commonly used devices for the preparation of weakly electrolyzed reduced alkaline water. The main structure of this machine generally includes power supply, electrolyzer, electrode and selective penetration membrane. The produced water quality and quantity is mainly depended on the structure and operation of the preparation device. This study simulated the water production process of the household electrolytic water machine and explored the best preparation conditions.
2. Material and methods

2.1. Experiment setup and operation procedure

In this experiment, a self-designed and assembled weakly electrolyzed reduced alkaline water generating device was adopted which can effectively control the operating condition. As Figure 1, the device mainly includes three parts: power, pretreatment device (water purifier) and electrolyser. During the experiment, municipal tap water was firstly poured into water purifier and then injected into the electrolyzer (Figure 2).

![Physical diagram of self-made low alkaline electrolytic primary water generating device.](image1)

**Figure 1.** Physical diagram of self-made low alkaline electrolytic primary water generating device.

![Flow chart of preparation](image2)

**Figure 2.** Flow chart of preparation

2.2. Single factor method

Single factor method was used to optimum preparation conditions to produce weakly electrolyzed reduced alkaline water. The effect of electrolytic voltage, electrolytic time and electrode interval on water quality was respectively analyzed by single factor method, as follows:

- Under electrode interval of 10 mm and electrolytic time of 1 min, the voltage was adjusted from 5V, 10V, 15V, 20V, 25V to 30V, respectively. After that, pH and ORP value of the water were measured.
- The effect of electrode spacing (10 mm, 15 mm, 20 mm, 25 mm and 30 mm) on water quality was studied under voltage 10 V and the electrolytic time 1 min. In the experiment of the effect of electrolysis time (1 min, 2 min, 3 min, 4 min and 5 min) on the water quality with the electrode interval 10 mm and the electrolytic voltage 10 V.

2.3. Orthogonal experiment method

Optimum preparation conditions of electrolyte water were conducted by orthogonal method according as following describe:

Standard orthogonal table L9 (34) was selected, and the orthogonal experiment design assistant was used to carry out the experiment design. The specific factors and horizontal distribution are shown in Table 1, and the experimental scheme is arranged as shown in Table 2.
Table 1. The orthogonal experiment in three factors and three levels.

| Level | Electrolytic voltage (V) | Electrode interval (mm) | Electrolytic time (min) |
|-------|---------------------------|-------------------------|--------------------------|
| 1     | Ten                       | Ten                     | 1                        |
| 2     | Fifteen                   | Fifteen                 | 2                        |
| 3     | Twenty                    | Twenty                  | 3                        |

Table 2. The orthogonal experimental design method in three factors and three levels.

| Serial number | A Electrolytic voltage (V) | Empty column | B Electrode interval (mm) | C Electrolytic time (min) |
|---------------|----------------------------|--------------|---------------------------|----------------------------|
| 1             | 1 (10)                     | 1            | 1 (10)                    | 1 (1)                      |
| 2             | 1                          | 2            | 2 (15)                    | 2 (2)                      |
| 3             | 1                          | 3            | 3 (20)                    | 3 (3)                      |
| 4             | 2 (15)                     | 1            | 2                         | 3                          |
| 5             | 2                          | 2            | 3                         | 1                          |
| 6             | 2                          | 3            | 1                         | 2                          |
| 7             | 3 (20)                     | 1            | 3                         | 2                          |
| 8             | 3                          | 2            | 1                         | 3                          |
| 9             | 3                          | 3            | 2                         | 1                          |

2.4. Response surface method

In this experiment, response surface method was used to verify the regression relation between key influencing factors (electrolytic voltage, electrode interval and electrolytic time) and electrolysis conditions.

In this paper, using MATLAB software, and using the data obtained from single factor experiment and orthogonal experiment, we set up a suitable mathematical model, and analyze the experiment index (pH, ORP) and electrolysis conditions. According to their regression relation, draw a corresponding relation graph.

2.5. Analytical methods

pH and ORP were chosen to evaluate water quality of electrolyzed reduced alkaline water which were measured by the HI98194 portable multi-parameter water quality analyzer (HANA, Italy). All of the experiments and analysis were conducted in triplicate and the results were expressed in average. The experiment data is processed by using the Origin 9.0 (OriginLab, US).
3. Results and discussions

3.1. Influence of electrolytic voltage

**Table 3.** Different electrolytic voltage and corresponding discharge index.

| V (V) | 5   | Ten | Fifteen | Twenty five | Thirty |
|-------|-----|-----|---------|-------------|--------|
| pH    | 7.7 | 8.37| 8.9     | 9.17        | 9.33   | 9.50  |
| ORP   | 66  | 38  | 34      | 11          | 9      | -16   |

![Figure 3. Influence of different electrolytic voltage on water quality](image1)

![Figure 4. Influence of different electrode spacing on water quality](image2)

Table 3 and Figure 3 shows the pH and ORP values of the electrolyzed reduced alkaline water with voltage increased from 5V to 30V. The electrolytic voltage has great influence on the pH and ORP values of electrolyzed reduced alkaline water. pH value increases continuously with the increase of electrolytic voltage especially when the voltage lower than 15V. The pH value increased slowly when voltage higher than 15V, and kept around 9.50 under 30V. The ORP value exhibited a conversely variation trend compared with pH which was decreased from 66 mV to -16 mV. According to the pH and ORP variation, the suitable voltage value was between 10V and 20V, and this voltage range is agreement with the limit voltage range (between 3V and 2V).

3.2. Influence of electrode interval

**Table 4.** Different electrode spacing and corresponding discharge index.

| H (mm) | Ten | Fifteen | Twenty | Twenty five | Thirty |
|--------|-----|---------|--------|-------------|--------|
| pH     | 8.53| 8.31    | 8.13   | 7.88        | 7.87   |
| ORP    | 45  | 44.5    | 118.5  | 127         | 127.5  |

Under the condition that the electrolytic voltage was 10V and the electrolytic time was 1 min, the influence of electrode interval was shown in Table 4 and Figure 4. According to the above experiment results, the electrode interval also influenced pH and ORP values of electrolyzed reduced alkaline water. With the increase of the pole interval, pH slightly decreased from 8.53 to 7.87 and the ORP
significantly increased from 45 mV to 127.5 mV. It can be concluded that decrease the distance of electrodes was benefit for the quality of produced electrolyzed reduced alkaline water. However, the small electrode distance means less water between two electrodes, which would result in a lower ion exchange effect. After comprehensive consider the water quality and water quantity, the pole interval between 10 mm and 20 mm was thought as the most suitable.

3.3. Effect of electrolysis time

Table 5. Different electrolysis time and corresponding discharge index.

| T (min) | pH  | ORP (mV) |
|---------|-----|----------|
| 0       | 7.56| 176      |
| 1       | 8.42| 41       |
| 2       | 8.99| 8        |
| 3       | 9.32| -35      |
| 4       | 9.34| -75      |
| 5       | 9.38| -112     |

Figure 5. Effect of different electrolysis time on water quality

Table 5 and Figure 5 listed the influence of electrolytic time on the electrolyzed reduced alkaline water quality. From Figure 5, electrolysis time has great influence on pH and ORP values of electrolyzed reduced alkaline water. The pH significantly increased from 7.56 to 9.32 in the first 3 min, and after that, pH value kept stable around 9.3 with electrolysis time increased to 5 min indicating that raw water was completely ionized in 3 min. The ORP value kept decrease during 5 min. In 1 min, the pH value can reached low alkaline condition, while the negative ORP value need more time (3 min). It can be seen that to prepare the electrolyzed reduced alkaline water the electrolysis time should more than 1 min. Comprehensive electrode life and energy consumption, the optimum electrolysis time is 1-3 min for the electrolysis device.

3.4. Best preparation conditions

3.4.1. Analysis of orthogonal experiment. According to the results of electrolytic voltage, electrode interval and electrolytic time on the quality of electrolyzed reduced alkaline water, the suitable range of electrolytic conditions was listed in Table 6, and the visual analysis results are shown in Table 7.

Table 6. Three factors three level orthogonal experiment results.
All of the nine conditions in Table 6 could produce electrolyzed reduced alkaline water with low alkalinity pH value (8.5 and 9.5) and negative ORP value indicated that the range of electrolytic conditions selected in Table 6 is suitable.

Table 7. Three factors-level visual analysis results.

| Factor | Electrolytic voltage(V) | Empty column | Electrode interval (mm) | Electrolysis time(min) |
|--------|--------------------------|--------------|-------------------------|-----------------------|
| K1 (pH)| 8.87                     | 9.03         | 9.25                    | 8.71                  |
| K2 (pH)| 9.11                     | 9.20         | 9.11                    | 9.22                  |
| K3 (pH)| 9.35                     | 9.10         | 8.97                    | 9.39                  |
| R (pH) | 0.48                      | 0.17         | 0.28                    | 0.68                  |
| K1 (ORP)| -29.42                 | -37.12       | -63.05                  | -13.72                |
| K2 (ORP)| -46.65                 | -53.22       | -46.33                  | -51.38                |
| K3 (ORP)| -58.63                 | -44.37       | -25.32                  | -69.60                |
| R (ORP) | 29.22                   | 16.10        | 37.73                   | 55.88                 |

According to the range analysis of pH value and ORP value in Table 7, for the pH value, the influence of electrolytic time was largest following with electrolytic voltage and electrode interval. For water ORP value, the electrolytic time was the most important influencing factor following with electrode...
interval and electrolytic voltage. The empty column has very little effect compared with other factors; therefore the interaction can be ignored in this experiment.

The principle of optimum preparation conditions selection, on one hand, the water pH value is the higher the better (should less than 9.5) while the ORP value is the lower the better. On the other hand, the energy consumption should be consideration in practice. And from the user experience, electrolysis time should be as short as possible. Therefore, A1B2C2 was thought as the optimum scheme in this experiment, that is to say, the electrolytic voltage is 10v, the electrode spacing is 15 mm and the electrolytic time is 2 min.

3.4.2. Analysis of response surface. The pH and the quadratic regression equations of the electrolyzed reduced alkaline water were established by MATLAB software:

(a) Analysis of the responsiveness of pH and the electrolytic conditions:

The pH and the quadratic regression equations of the electrolyzed reduced alkaline water were established by MATLAB software:

\[
D=7.5101+0.0954A+0.0319B+0.2017C-0.0002A^2+0.008B^2-0.0142C^2-0.0045AB+0.0113AC-0.0051BC
\]

in which D is pH, A is electrolytic voltage (V), B is electrode spacing (mm), and C is electrolytic time (min).

(b) Analysis of the responsiveness of ORP and the electrolytic conditions:

The ORP and the quadratic regression equations of weak alkaline electrolytic primary water using MATLAB software are as follows:

\[
D=102.8266-9.0280A-4.4568B-24.2071C+0.1154A^2+0.0952B^2+1.7188C^2+0.2811AB-0.7671AC+0.1796BC
\]

where D is ORP value, A is electrolytic voltage (V), B is electrode spacing (mm), and C is electrolytic time (min).

At the same time, three statistics obtained from the above model (Figure 7): the fitting degree R²=0.9391, the statistical observations value F=15.4079, and the examine P=0.00018. It is known that when the R² is greater than 0.9 and closer to 1, and the F value is greater, the model fitting degree is higher and the correlation is better. When p value less than 0.05 illustrate that the model is effective. Therefore, the above model is effective and has high similarity and correlation.
4. **Conclusion**
(a) Electrolytic time, electrolytic voltage and electrode interval could influence the water quality of the electrolyzed reduced alkaline water. More electrolysis time, higher of electrolytic voltage, and smaller electrode interval resulted in higher water pH value. More electrolysis time, higher electrolytic voltage, and larger electrode interval resulted in lower water ORP value.
(b) The optimum condition for preparation of weak alkaline primary water is 10v electrolytic voltage, 15 mm interval of electrodes and 2 min electrolysis time.
(c) High fitting degree and correlation regression relations were established between water quality (pH and ORP values) and operation conditions (electrolytic voltage (A), electrode interval (B) and electrolytic time (C)):
   
   **pH:** \[ D = 7.5101 + 0.0954A + 0.0319B + 0.2017C - 0.0002A^2 - 0.0008B^2 - 0.0142C^2 - \\
   0.0045AB - 0.0113AC - 0.0051BC \]
   
   **ORP:** \[ D = 102.8266 - 9.0280A - 4.4568B - 24.2071C + 0.1154A^2 + 0.0952B^2 + 1.7188C^2 + 0.2811AB - \\
   0.7671AC + 0.1796BC \]

5. **References**
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