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Experimental Evaluation of Water Contamination in a Non-Thermal Food Processing System Utilizing an Underwater Shockwave

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***Abstract*:** *Recently, as a low-cost non-thermal food processing technique, the food processing technique utilizing an underwater shockwave is receiving much attentions. In the non-thermal food processing system, the underwater shockwave is generated by discharging a high voltage between metal electrodes, where copper electrodes or aluminium electrodes are usually used as electrode materials in order to perform the non-thermal food processing. By utilizing underwater shockwaves, only the internal tissue of a target food can be disrupted without heating. However, a part of the electrodes is melted by the high electric discharge. In this paper, we focused on water contamination caused by the metal electrode which dissolved in water. As far as the authors know, the water contamination has not been investigated in past studies, though there is a possibility that the water contamination has an influence on human bodies. In this paper, we conducted the experimental evaluation of water contamination in the non-thermal food processing system utilizing an underwater shockwave. By using a water examination device, the contamination caused by copper electrodes was investigated for 100 samples. The experimental result showed that the copper concentration in the water of the pressure vessel was 0.33 mg/L at 17.5 degrees Celsius. The degree of thickness of the contaminated water was less than the standard copper value in the water quality standard for Japanese drinking water.*

Keywords: *Cockcroft-Walton multipliers, Non-thermal food processing, Underwater shockwaves, Water contamination.*

1. Introduction

For our healthy life, the development of effective food processing technologies is a vital issue. In recent years, non-thermal food processing [1] attracts many researchers' attention, because the non-thermal food processing technology can provide nutritious foods without destroying nutrients with an increase in temperature. For this reason, several types of non-thermal food processing technologies have been developed in past studies, for example, High Hydrostatic Pressure (HHP), High Voltage Arc Discharge (HVAD), and Cold Plasma (CP). Among others, we focused on the non-thermal food processing technology utilizing an underwater shockwave [2, 3], because it is advantageous in regards to cost.

In the first non-thermal food processing system, explosive was used to generate an underwater shockwave. However, due to the safety reasons, a high voltage multiplier is used to generate the underwater shockwave in recent years. The operation principle of a current non-thermal food processing system is as follows: First, a high stepped-up voltage which is generated by the high voltage multipliers is stored in a big capacitor. Then, electrical energy stored in the big capacitor is discharged in a pressure vessel filled with water. In this timing, a

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large current flows between electrodes and the electrical energy turns into shockwave energy in the pressure vessel. Finally, only the internal tissue of the target food is disrupted by underwater shockwaves.

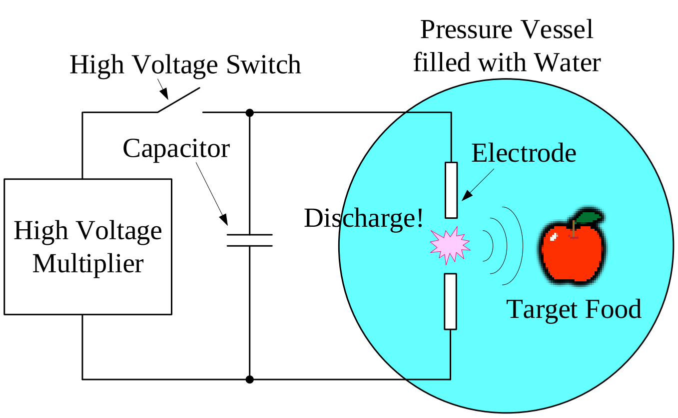
The main component of this non-thermal food processing system is the high voltage multiplier and the pressure vessel. In past studies, many researchers have tackled to develop efficient non-thermal food processing systems. For example, the development of the pressure vessel has been studied in [4-6], for example, Miyafuji et al. and Iyama et al. proposed the pressure vessel for manufacturing rice powder in 2011 [4] and 2016 [5]. Furthermore, Higa et al. analyzed the characteristics of the shockwave propagation by computer simulation [6]. On the other hand, the high voltage multiplier has also been studied by many researchers, for example, an inductor-less high-speed CWVM [7, 8] was proposed by Eguchi et al. and Abe et al. in 2014 and 2015. Following this studies, in order to increase step-up gain, series-connected high voltage multiplier [9] was suggested by Abe et al. in 2017. Owing to these studies, the non-thermal food processing system became to be able to process a target food effectively. However, as far as the authors know, water contamination in the pressure vessel has not been discussed in past studies. In the non-thermal food processing system, copper electrodes or aluminium electrodes are usually used as electrode materials. In the discharging process, a part of the electrodes is melted by a large current which flows between electrodes. For this reason, there is a possibility that the metal electrode which dissolved in water has an influence on human bodies.

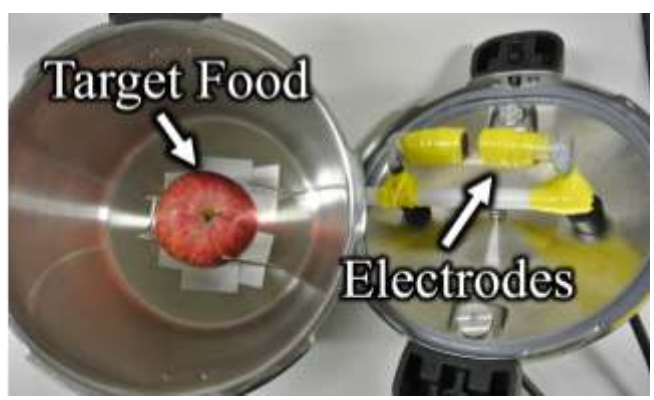
In this paper, we conduct the experimental evaluation of the water contamination in the non-thermal food processing system utilizing an underwater shockwave. By using a water examination device, the contamination caused by copper electrodes is investigated for 100 samples. This work will contribute to the development of the non-thermal food processing system utilizing an underwater shockwave, because the influence on human bodies is the most important issues in the food processing systems.

The rest of this paper is organized as follows: Section 2 shows the configuration of the non-thermal food processing system and explains the operation principle of the non-thermal food processing system in detail. Section 3 demonstrates the experimental evaluation of the water contamination through laboratory experiments. Finally, section 4 discusses conclusion and future work of this study.

2. System Configuration

Figure 1 illustrates the system configuration of the non-thermal food processing system utilizing an underwater shockwave. By utilizing underwater shockwaves, the non-thermal food processing system of figure 1 can disrupt only the internal tissue of a target food without heating. As figure 1 (a) shows, the non-thermal food processing system is mainly composed of a high voltage multiplier, a big capacitor, a high voltage switch, and a pressure vessel. The operation principle of the proposed system is as follows.





(a) (b)

Fig. 1: System configuration of the non-thermal food processing system utilizing an underwater shockwave: (a) block diagram of the non-thermal food processing system and (b) pressure vessel.

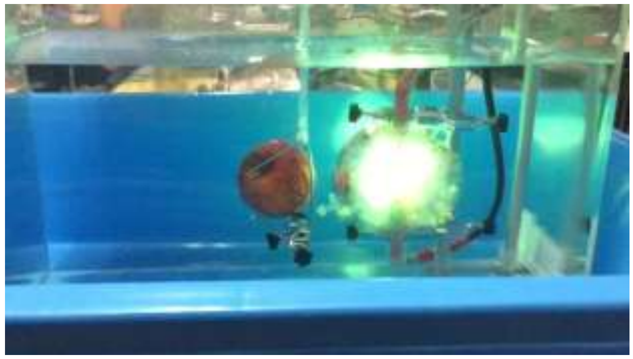


Fig. 3: Discharge process in the non-thermal food processing system utilizing an underwater shockwave.

First, a high stepped-up voltage, such as 3.5kV, is generated by converting an ac input voltage. The output voltage of the high voltage multiplier is stored in a big capacitor with 200μF capacity. Next, the electric charge stored in the big capacitor is discharged by turning on the high voltage switch. In this process, the water around electrodes evaporates instantaneously by a large current. Finally, a shockwave occurs by implosion. In this process, the target food is destroyed by internal destruction which is called spalling destruction. Figure 1 (b) shows an example of the electrodes and the pressure vessel to fill water, where copper electrodes are used to flow a large current at low cost. However, during electric discharge, a part of the electrodes is melted by the large current. Figure 3 demonstrates an example of the discharging process in the non-thermal food processing system utilizing an underwater shockwave. It is obvious that the copper electrodes are melted by high electric discharge, because the flame colour is green.

In the next section, we will evaluation of water contamination in the non-thermal food processing system.

3. Experiment

3.1. Experimental Setup

To evaluate contamination of water in a pressure vessel, experiments were conducted by using the laboratory prototype shown in figure 4. As figure 4 shows, the experimental circuit consists of a high voltage multiplier, a high voltage relay, a big capacitor, and a pressure vessel shown in figure 1 (b). The experimental conditions are as follows: the input voltage of the high voltage multiplier is 100V@60Hz, the output voltage of the high voltage multiplier is 3.5 kV, the capacity of the big capacitor is 200μF with 4000VDC rated voltage, the HV contact of the high voltage relay is 12 kV, the insulation to ground of the high voltage relay is 20 kV, the capacity of the pressure vessel is 5.5 liters, the diameter of the copper electrode is 10mm, and the space between electrodes is 10mm.

(a) (b)

Fig. 4: Laboratory prototype used in experiments: (a) over view and (b) electrodes.

3.2. Experimental Evaluation

By using a water examination device, the water contamination in the pressure vessel was investigated for 100 samples. Figures 5 and 6 demonstrate the experimental results, where figure 5 shows the histogram of copper concentration, figure 6 (a) shows the copper concentration vs. resistivity, and figure 6 (b) shows the copper concentration vs. water temperature. From the experimental results of figure 5, the average copper concentration in the water of the pressure vessel was 0.33 mg/L at 17.5 degrees Celsius. In the water quality standard for Japanese drinking water, the standard copper value is less than 1mg/L. Therefore, the water contamination caused by copper electrodes does not influence the human bodies seriously. Furthermore, as figure 6 shows, the copper concentration has no relation with the resistivity and temperature of water.

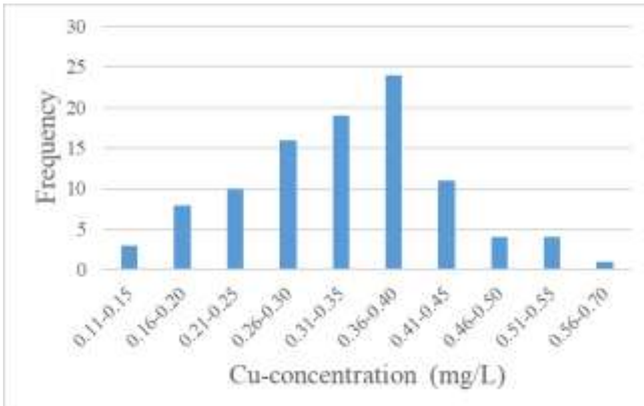
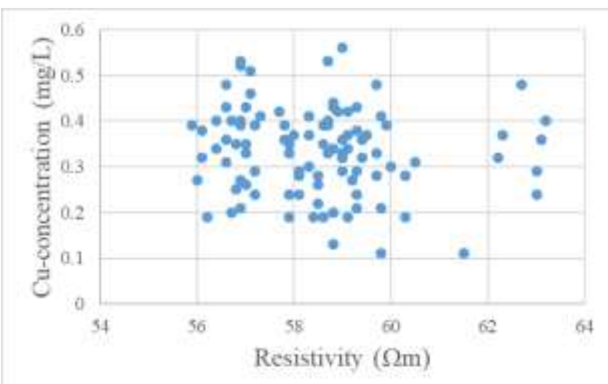
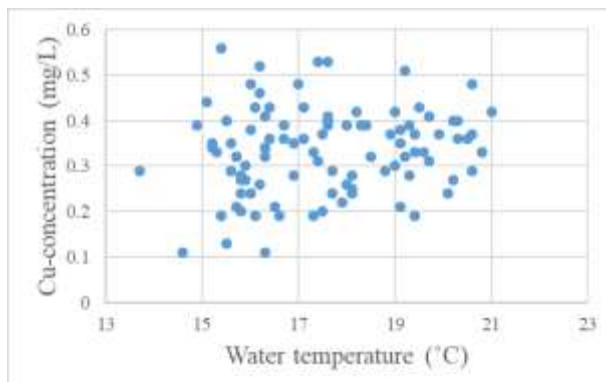


Fig. 5: Histogram of Cu-concentration.



(a)



(b)

Fig. 6: Laboratory prototype used in experiments: (a) Cu-concentration vs. resistivity and (b) Cu-concentration vs. water temperature.

4. Conclusion

In this paper, the water contamination was investigated concerning the non-thermal food processing system utilizing an underwater shockwave. By using a water examination device, the experiment was conducted for 100 samples. The experimental result showed that the degree of thickness of the contaminated water is less than the standard copper value in the water quality standard for Japanese drinking water. Concretely, the copper concentration in the water of the pressure vessel was 0.33 mg/L at 17.5 degrees Celsius.

This work will contribute to the development of the non-thermal food processing system utilizing an underwater shockwave, because the influence on human bodies is the most important issues in the food processing systems. The experimental evaluation of water contamination caused by other metal electrodes, such as aluminium electrodes, is left to a future study.

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