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Decomposition of Cellulose by Ultrasonic Welding in Water
液中超音波溶接によるセルロースの分解

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1. Introduction

Cellulose, a type of saccharide that is the main component in cell walls of plants, is the most prevalent organic compound existing in nature. Decomposition of cellulose to smaller molecules is difficult due to its strong crystalline structure formed by intermolecular hydrogen bonds. At present, it is discarded in large quantities without any effective utilization.

Application of ultrasonic waves is under investigation in many fields for a variety of purposes, because of its high energy efficiency and strong decomposition power. It has the added bonus of requiring minimal operation time requirements greatly reducing its load on the environment. Ultrasonic welding technology is a processing technique that instantly bonds a target material by ultrasonic wave vibration combined with a pressurization power. It is proposed that cellulose can be broken down into smaller molecules effectively by hydrolysis using frictional force caused by ultrasonic wave irradiation and pressurization power.

In this study, in order to produce hydroxyl methyl furfural (5-HMF), furfural and glucose, small molecules that all have high utility value, from the polysaccharide, cellulose, , filter paper consisting of cellulose was irradiated with ultrasonic waves focused by a horn-type concentrator emitting ultrasonic waves toward the bottom of the reaction container.

2. Experimental Apparatus and Method

A diagram of the experimental apparatus is shown in Fig. 1. The reaction container is structured to hold the target object securely by tapering the shape of the reaction space. Ultrasonic waves of 19.5 kHz are emitted downward from a horn-type transducer. Output power of ultrasonic waves to the object is measured using a wattmeter. As an target, filter paper (Orient filter paper Co., Ltd.) which has a high cellulose content was used. Eight pieces of the filter paper were stacked at the bottom of the reaction container, and were submerged in 5 mL of pure water. As an experiment procedure, a high-frequency oscillator induced ultrasonic wave irradiation after that, a forwarding steering wheel maintained focus on the filter paper continued during the experiment. After the experiment, the liquid remaining in the reaction container was collected, and the ingredients of the product were analyzed by liquid chromatography.

3. Experimental Results

The results by liquid chromatography are shown in

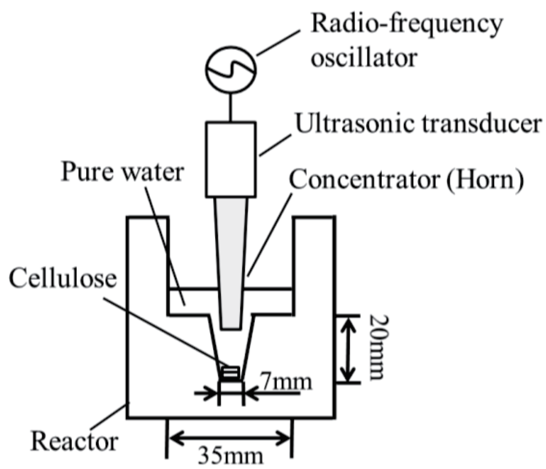

Fig.1 Experimental apparatus.

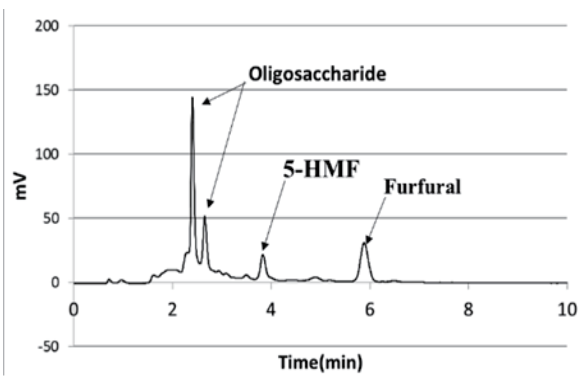

Fig.2 Liquid chromatograph analysis after ultrasonic irradiation.

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Fig. 2. The output power of the ultrasonic waves was 100 W and the irradiation time was 60 seconds. It was confirmed that 5-HMF, furfural and oligosaccharides were present in the liquid, whereas glucose was not confirmed. With the output power as the X-axis, production of 5-HMF and furfural is shown in Fig. 3. The irradiation time is 60 seconds. Production of 5-HMF and furfural increased as output power increased.

Production of 5-HMF and furfural according to irradiation time is shown in Fig. 4. The output power is 100 W, and irradiation time of the ultrasonic waves is shown on the X-axis. Production of furfural and 5-HMF increased with the irradiation time. The increase in the production of furfural was remarkable, increasing 4.6 times at 180 seconds over that at 15 seconds.

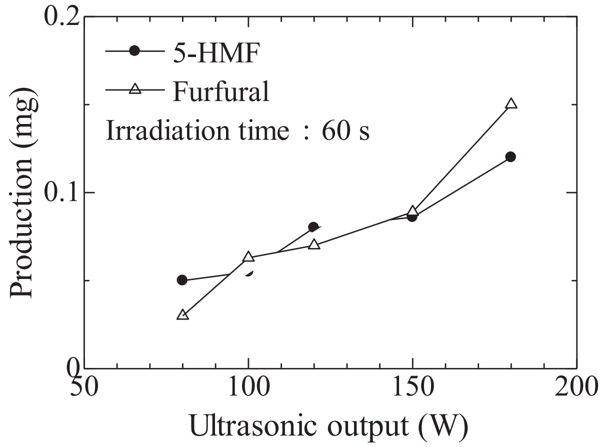

Fig.3 Production of 5-HMF and furfural at 60 s.

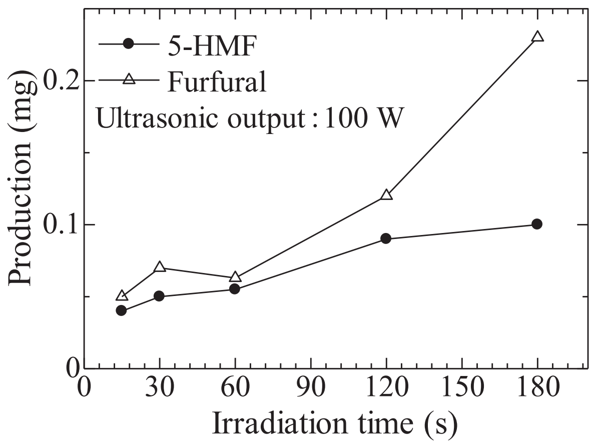

Fig.4 Production of 5-HMFand furfural at 100 W.

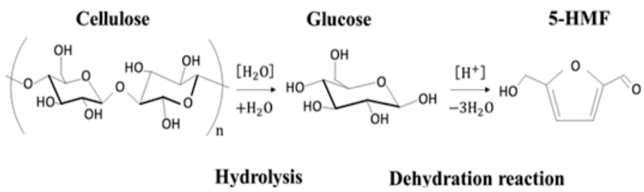

Fig.5 Decomposition process of cellulose.

4. Discussion

In the products, 5-HMF and oligosaccharides were confirmed in the liquid remaining after the experiment by liquid chromatography, though glucose was not. The general reaction sequence to 5-HMF from cellulose is shown in Fig. 5. First, monosaccharides are produced from cellulose by hydrolysis, and then 5-HMF is produced from the glucose by dehydration reaction. However, because there was no glucose in the remaining liquid, it is considered that the ultrasonic waves produce 5-HMF from oligosaccharides by a dehydration reaction without cutting off the cellulose compound. In addition, a temperature rise in the reaction container was confirmed after long-time ultrasonic wave irradiation. Because 5-HMF is vulnerable to heat, the increase of the production of 5-HMF was moderated by the ultrasonic wave irradiation time. In addition, the production of the furfural by thermal decomposition of the cellulose suddenly increases at 250°C to 350°C(1). The reason for the sudden production increase of the furfural at 180 seconds is that local temperature of the reaction environment reaches 250°C.

5. Conclusion

Filter paper consisting of cellulose was irradiated with ultrasonic waves of 19.5 kHz focused by a horn-type concentrator emitting ultrasonic waves toward the bottom of the reaction container. The ingredients of the liquid remaining after the experiment were analyzed by liquid chromatography. In the products, 5-HMF, furfural and oligosaccharides were confirmed in the remaining water, though glucose was not. Production of furfural and 5-HMF increased with ultrasonic wave irradiation time. The increase in production of the furfural was remarkable and rose by 4.6 times at 180 seconds compared to that at 15 seconds.

References

1. K. Kato, T. Doihara, and F. Sakai: Japan Society for Bioscience, Biotechnology, and Agrochemistry **40** (1966) 443 [in Japanese].