Proposal for a Low-Cost Water Level Sensor without External Power Using MFC

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***Abstract*—In this study, a water level sensor based on Microbial Fuel Cells (MFC) is proposed. The objective is to realize a low-cost water level sensor that does not require external energy. Copper was used as one of the cathode materials to sustain the output voltage of the MFC. Several cathodes were used to estimate the water level position. Sensing was also performed in two liquids with different Chemical Oxygen Demand (COD) values. As a result, water level fluctuations could be immediately ascertained from changes in output voltage. Furthermore, it was confirmed that the sensor reaction time was not affected by differences in COD values.**

***Keywords*—Microbial Fuel Cells (MFC), water-level sensor, copper cathode, low cost, external powerless, muddy water**

I. Introduction

In recent years, technology has made great strides and is being used to make people's lives more comfortable. Water level sensors are one such example. They play an important role in monitoring the water levels in water storage tanks used in industry and agriculture [1] and in controlling floods and accidents [2] in rivers, dams, and reservoirs.

However, ultrasonic water level sensors [3] and capacitive water level sensors [4] currently in use are costly and require external energy.

Many regions of the world, such as Nepal, are suffering from severe energy crises. Energy crises have a negative impact on economic and social systems [5], so we turned our attention to Microbial Fuel Cells (MFCs), which do not require external energy and are cost-effective.

MFCs are devices that use the organic matter decomposition properties of current-generating bacteria (such as Schwanella [6]) present in rivers, soil, and wastewater to extract electrical energy. Electrons generated by these microorganisms are collected at the anodes. The collected electrons reach the cathode via an external circuit and are received by electron acceptors (such as oxygen) [7]. Through this sequence of events, it is possible to generate electrical energy. This technology is expected to enable a low-cost water level sensor that does not require external energy.

In this experiment, we propose a water level sensor using MFC. Two cathodes were used to measure water level fluctuations. The cathode in contact with water can receive protons from the anode. When the cathode is no longer in contact with water, the voltage becomes zero. Thus, the water level is measured from the location of the cathode where the voltage is observed.

This system allows the sensor to perform its role using only internal power. Furthermore, cost reduction was achieved by using low-cost materials as electrode materials.

The electrodes for the anode and cathode were made of different materials. For the anode, a mixture of Rice Husk Smoked Charcoal (RHC) and Sumi ink was used. Sumi ink is a liquid black ink obtained by grinding Sumi with water, which has been used in Japan since ancient times. Since carbon black is a major component, it is highly conductive and has the characteristic of solidifying when dried [8]. Taking advantage of this characteristic, the material was poured into an anode mold and solidified. For the cathode, a mixture of RHC, copper powder, and Sumi ink was used. Copper has been shown to have antimicrobial properties and prevent and control biofilm formation on the cathode surface [9]. The copper suppresses electron collection on the cathode surface and is expected to sustain voltage output.

II. Literature Review

MFC has been applied in various fields because of its unique ability to convert organic materials into electrical energy. An example is Biochemical Oxygen Demand (BOD) sensors. These sensors use the voltage difference between the anode and cathode to determine the BOD value [10].

In other words, the sensor plays a role by measuring changes in the organic matter decomposition activity of microorganisms.

We propose a new sensor for measuring water level by applying this microbial activity.

III. Materials and Methods

A. Preparation of Anodes and Copper Cathodes

RHC (Tokorozawa Planting Bee Center, Saitama, Japan) obtained by the smoking method [11], a standard treatment of rice husks in farmers, was used RHC was stirred into an aqueous NaOH solution for etching. 1.8 g of powdered RHC mixed with 7 ml of Sumi ink (Kuretake Co., Ltd., Japan, Nara) was poured into a mold 2 cm long, 2 cm wide, and 1 cm high, and dried and hardened for about 1 day along with a hardened stainless steel mesh (SSM, 304-100 mesh).

The completed product was used as an anode (Fig. 1 (a)). A mold shaped as shown in Fig. 1(b) was prepared and used as the cathode. First, copper powder was mixed at a ratio of 1 g of copper powder to 30 ml of Sumi ink and stirred at 800 rpm for about 3 hours using a magnetic stirrer.

The finished product is called copper Sumi ink. Next, 3 ml of copper Sumi ink and 0.6 g of smoked charcoal per cathode were mixed and poured into a mold, then dried for about one day together with a hardened stainless steel mesh. The cathodes are rectangular in shape, 2 cm long, 1 cm wide and 1 cm high.

A flexible stainless steel mesh (#400φ0.03, CLEVER, Aichi, Japan) was used to connect the anode and cathode by bringing it into contact with the rigid stainless steel mesh.

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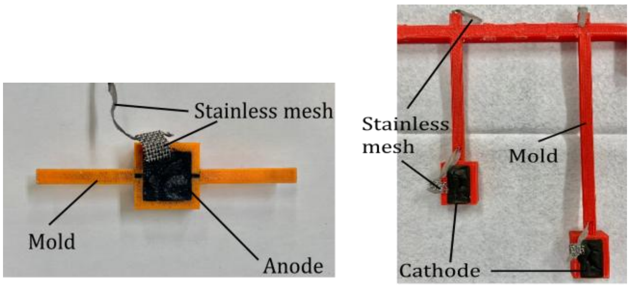

(a) (b)

Fig. 1. (a) Photograph of the anode. (b) Photograph of the cathodes.

B. Preparation of LB Medium and Biofilm

In this experiment, Lysogeny Broth (LB) medium was prepared by mixing 500 ml purified water, 5.0 g tryptone, 2.5 g yeast extract, 5.0 g sodium chloride, and 2.5 ml sodium hydroxide solution (concentration about 1.23%) LB medium was sterilized at 121°C for 30 min, diluted 5 times with tap water, and used for measurements. Prior to the experiment, the anodes were soaked in soil (collected from an open area on the Biwako Kusatsu Campus of Ritsumeikan University) for one week to generate a biofilm on the surface.

C. Structure and Setup of Water Level Sensor

The molds for the electrodes were created using a 3D printer. Acrylonitrile-Butadiene-Polystyrene (ABS) resin was used as the material. The entire device was fixed in a transparent plastic case, and the water level varied up and down. To avoid short circuits between adjacent cathodes, the cathodes are horizontally spaced, as shown in Fig. 2. Fig. 3 shows a schematic of the circuit during the experiment. The anodes were kept fully immersed, and the two cathodes were each connected to a 10 kΩ external resistor and a digital multimeter (NT8233D PRO, Neoteck) to measure the voltage difference between the anodes and cathodes.

To distinguish the two cathodes, they are named Cathode 1 and Cathode 2 from the bottom, as shown in Fig. 4. The spacing between cathodes was set at 2 cm due to the container used in this study. This spacing can be changed depending on the application. The water level 1 cm below the bottom of cathode 1 is called water level A, and the water level 1 cm above the top of cathode 2 is called water level B.

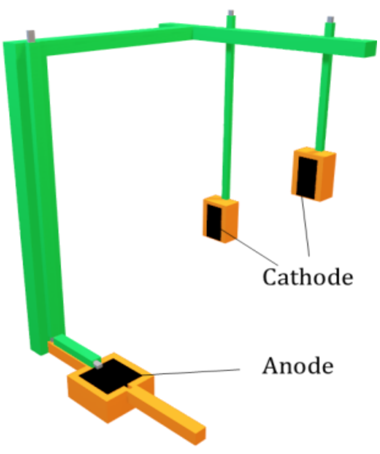

Fig. 2. Electrode arrangement.

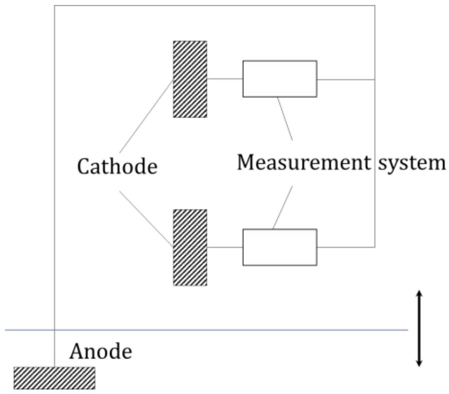

Fig. 3. Circuit schematic.

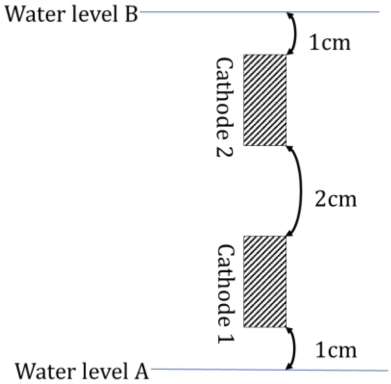

Fig. 4. Diagram of the cathodes and the water levels.

D. Water Level Changes and Measurement Methods

Experiments were conducted by the following two methods.

1) Sensing test using simulated wastewater

First, the operation of the water level sensor was checked using an LB medium to simulate a river and a water storage tank with high organic matter concentration. The output voltages of Cathode 1 and Cathode 2 were observed by changing the water level from Water level A to Water level B to Water level A at a constant rate.

2) Practical sensing test by using muddy water

Next, an experiment was conducted using muddy water (collected from a pond at the Biwako-Kusatsu campus of Ritsumeikan University) to confirm the operation in a common river and water storage tank. As with the LB medium, the water level was changed at a constant speed from Water level A to Water level B to Water level A, and the output voltages of Cathode 1 and Cathode 2 were observed.

IV. Result and Discussion

A. Biofilm Observation of Anode

Fig. 5 shows an image of the anode surface before the experiment using a Scanning Electron Microscope (SEM) (S-4300, Hitachi, Ltd., Japan). The image shows that the surface is covered with microorganisms. It can be confirmed that biofilm was formed by soaking in soil for about one week.

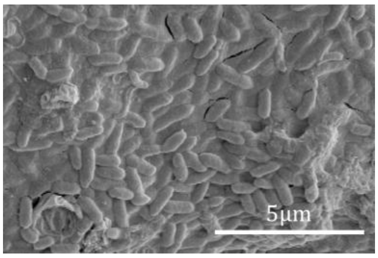

Fig. 5. SEM image of anode surface.

B. *Operation Results in Simulated Wastewater*

The experiment was conducted using an LB medium. Fig. 6 shows the measurement results of output voltage (upper panel) and the water level change (lower panel) when the water level was changed from (a) Water level A to Water level B and (b) Water level B to Water level A. Red vertical lines are drawn at the time when the cathode touched the liquid when the water level rose and at the time when the cathode completely left the liquid when the water level fell. From (a), a voltage increase occurred instantly at Cathode 1 when the water level was 10 mm and at Cathode 2 when the water level was 50 mm. Furthermore, from (b), the voltage dropped instantly at Cathode 2 when the water level was 50 mm and at Cathode 1 when the water level was 10 mm. Therefore, it was confirmed that it is possible to determine the water level position by observing the output voltage change of each cathode.

C. *Operation Results in Muddy Water*

The experiment was conducted using muddy water. Fig. 7 shows the measurement results of the output voltage (top) and the water level change (bottom) when the water level was changed from (a) Water level A to Water level B and (b) Water level B to Water level A, as in Fig. 6. The red vertical lines are drawn at the same time as in Fig. 6. The figure shows that even in muddy water, the voltage changed immediately with the water level, indicating that the position of the water level was known. The COD value of the LB medium used in the experiment above was 2956 mg/L, while the COD value of the muddy water was 272 mg/L. Therefore, there was a difference in the output voltage obtained. However, a comparison of Fig. 6 and Fig. 7 shows no significant change in the reaction rate of the cathode, confirming that the COD value did not affect the reaction rate.

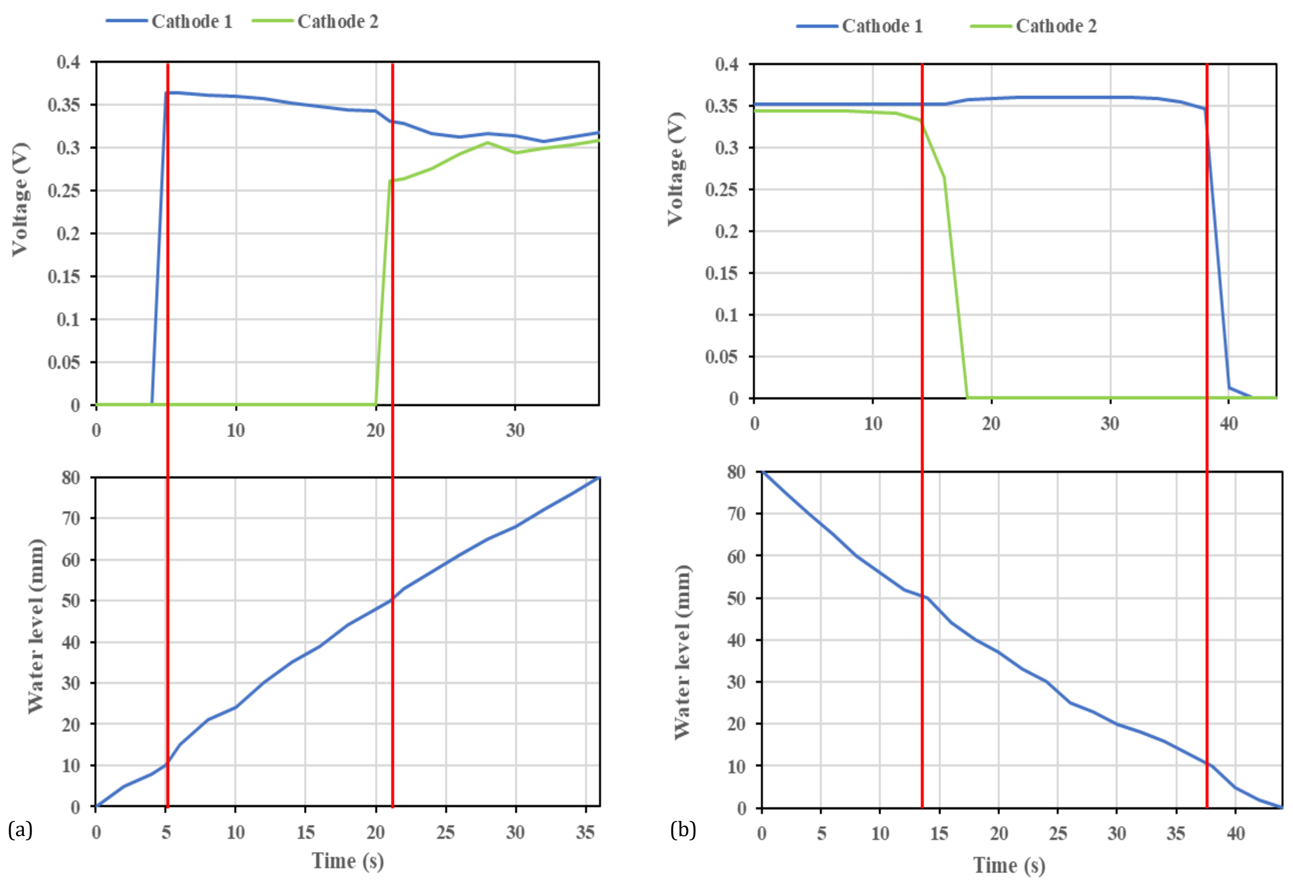

Fig. 6. Output voltage and the water level change with LB medium (a) from Water level A to Water level B and (b) from Water level B to Water level A.

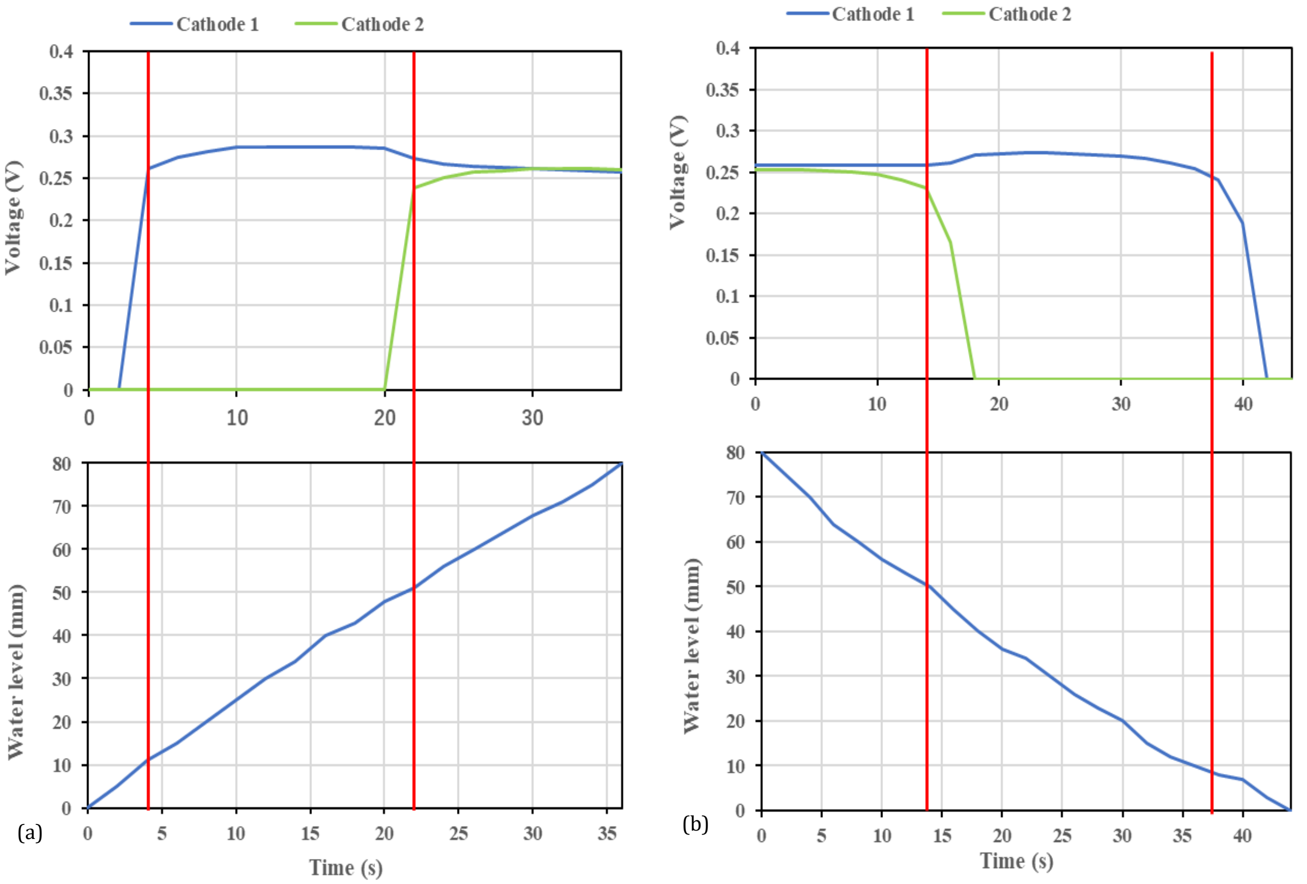

Fig. 7. Output voltage and the water level change with muddy water (a) from Water level A to Water level B, (b) from Water level B to Water level A.

V. CONCLUSION

This paper investigated the performance of a water level sensor using an MFC. It was shown that the output voltage of the MFC changes immediately with the position of the water level and that it is possible to determine the water level position. Anodes and cathodes could be easily fabricated from inexpensive materials. The sensor can be used in general rivers and water storage tanks as the sensor's response rate did not change with the COD value.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Kozo Taguchi conceptualized the research; Tomoya Yabuzaki and Soichiro Hirose analyzed the data; Tomoya Yabuzaki and Trang Nakamoto wrote the paper; and all authors approved the final version.

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