Discharge Characteristics of DC Arc Water Plasma for Environmental Application

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Abstract: The water plasma was generated by DC arc discharge with a cathode of hafnium embedded into a copper rod and a nozzle type copper anode. The discharge characteristics of the water plasma generation were examined with the change in working parameters of arc current and water feeding rate. The fluctuation of the arc movement on the anode was observed by using a digital oscilloscope and high speed camera. The stability of arc was also observed by optical emission spectrometry. The discharge characteristics of the water plasma affected by both physical and chemical factors were discussed for the application of waste decomposition.

Keywords: Thermal plasma, DC arc discharge, Water plasma, Arc movement

1. Introduction

Thermal plasma technology has been established as an important role in the many industrial fields such as plasma cutting, welding, plasma spraying, waste treatment, and synthesis of nanoparticles. The most widely used sources in these processes are the DC discharge operated in either transferred or non-transferred arc mode.

A non-transferred arc is generated between a cathode and nozzle working as an anode. This type of the arc discharge is suitable for various applications because this system does not need an external electrode. However, the plasma generation system generally requires complex sub-equipment such as gas-supply and cooling unit. Thus, efficient and simple plasma generation systems have been required for practical application.

The developed torch provides the generation of 100%-water plasma without commercially available steam generator [1,2]. The features of the torch results from the simple steam generation; liquid water in the reservoir is heated up and evaporates at the anode region to form the plasma supporting gas. Simultaneously, the anode is cooled by the water evaporation. Therefore, the electrodes require no additional water-cooling in the present water plasma torch. The distinctive steam generation method provides the portable light-weight plasma generation system that does not require the gas supply unit, thus the high energy-efficiency results from unnecessary of the additional water-cooling. These features of the proposed plasma generation method, which are not readily achieved by other methods, allow for simple and effective water plasma generation system.

The purpose of this paper is to investigate the discharge characteristics of DC water plasma and to optimize the discharge condition for the water plasma generator. Special attention is devoted to properties of DC water plasma that are important for performance characteristics in plasma applications.

2. Experimental

The experimental setup of water plasma generation system is shown in **Fig. 1**. The cathode of Hf with 1 mm in diameter was used for the plasma generation. The arc current was set from 5 A to 7 A, and the arc voltage was controlled within a range

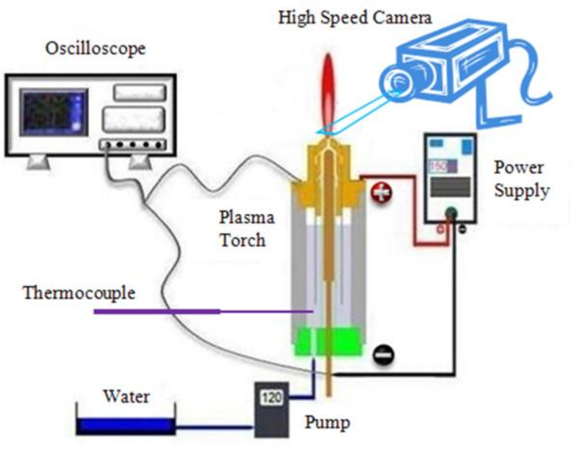

Figure 1. Experimental setup of water plasma system.

between 100 V and 200 V. The water to the plasma torch was supplied from 246 ml/h to 250 ml/h. The feeding rate was measured after 50 min from the arc ignition to obtain the stable arc generation. Thermocouple inside the plasma torch was used to measure the water temperature.

The arc voltages were measured by a digital oscilloscope (KEYENCE, GR-7000) with the sample interval of 0.2 μs. A high-speed video camera (NAC, MEMRECAM GX-8) was used to observe the arc movement at the nozzle exit with a frame rate of 300,000 fps.

3. Result and discussion

3.1 Arc movement

The side views of the plasma arc outside the nozzle exit are shown in **Fig. 2**. The interval between each photograph is 3.3 μs. The axial movement of arc is confirmed from these pictures of the side views. The arc was pushed out the nozzle exit by the plasma gas flow. When the arc was outside the nozzle exit, the arc was bent in the axial direction and the arc root appeared on the anode in the horizontal direction of the nozzle exit.

The voltage waveform is shown in **Fig. 3**. The periodic variation can be clearly found. The period from the valley to peak is several tens of kilohertz, indicating the characteristic arc movement. From the arc voltage recorded by oscilloscope and the photographs of the plasma jet taken by high speed video camera, periodic variation was caused by the movement of arc attachment on the anode in axial direction. The schematic diagram of the arc fluctuation is shown in **Fig. 4**.

From the voltage waveforms, the ratios of maximum values from the valley to peak to mean voltages were more than 100%. Therefore, the arc voltage of DC arc water plasma can be defined to be the restrike mode [3]. In the restrike mode, arc attachment on the anode firstly appears in the point on the anode which is closest to the cathode. At this time, the arc voltage reaches the minimum value since the arc length between cathode and anode is the shortest. Then, the arc attachment on the anode surface moves in the axial direction toward nozzle exit, causing the increase of arc voltage. Finally, the arc voltage reaches the furthest point on the anode from the cathode. At the time, the balance of electromagnetic force and gas drag force is destroyed and electromagnetic force is too weak to

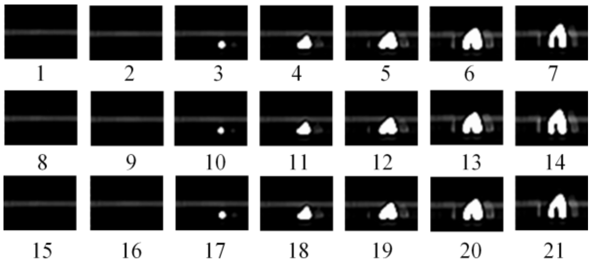

Figure 2. Images of the periodic variation of plasma arc from the side view at the nozzle exit. Pictures were taken at interval of 3.3μs; generation with Hf cathode, arc current of 13A.

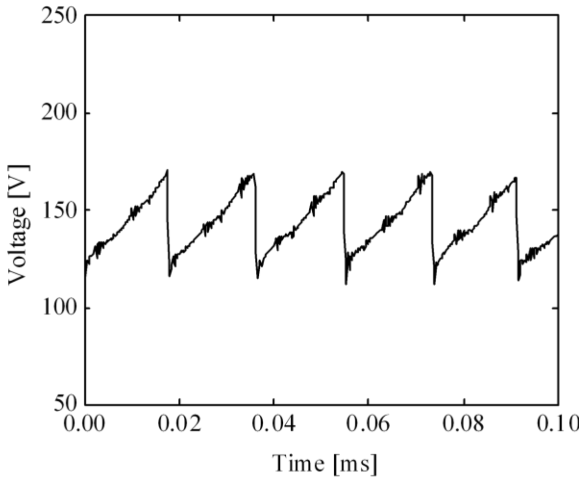

Figure 3. Voltage waveform with arc current of 13 A.

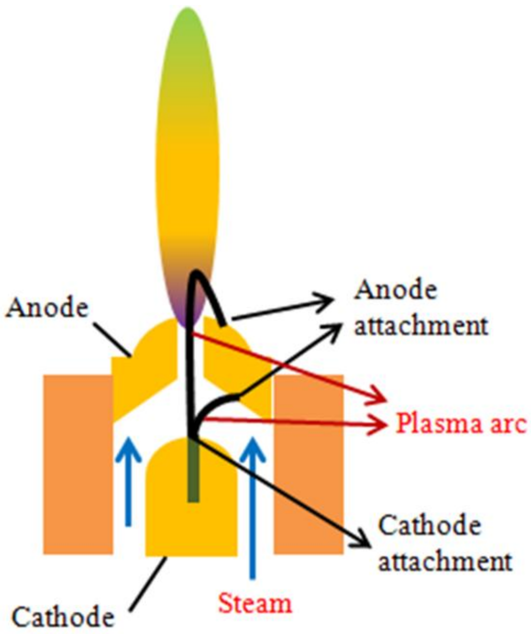

Figure 4. Arc movement mechanism.

support the existence of the long arc, thus causing the sudden breakdown of arc attachment, which is indicated by the sudden voltage drop from the peak to valley in the arc voltage waveform.

3.2 Effect of arc current

The photographs of the plasma jet at different arc currents are shown in **Fig. 5**. The flame of water plasma becomes larger at higher current of the arc. The frame of water plasma can be divided into three thermal regions on the base of the temperature distribution along the plasma jet, such as arc region, plasma flame region, and downstream region. The arc region was defined as a region between the electrodes, the plasma flame region was the higher temperature region (about 6000K) near the nozzle exit, and the downstream region was the lower temperature region (about 1000K) on the top of the plasma flame [4-6]. The frame of water plasma is very important in the plasma applications due to its high temperature. For example, in the waste treatment the decomposition efficiency can be influenced by the frame size of water plasma.

The voltage waveforms at different arc currents are shown in **Fig. 6**. The water plasma was generated with Hf 1 mm cathode and 2 mm distance between the cathode and anode. The water feeding rate was 248 ml/h. These figures indicate that the period of the valley to peak is shortened with increasing the arc current. The effect of arc current on the frequency of the arc fluctuation and the water temperature is shown in **Fig. 7**. The arc frequency increases with the arc current, because the water temperature increases with the arc current. Higher water temperature at higher arc current provides larger supply of water vapor into the arc region, resulting in higher frequency of the arc movement.

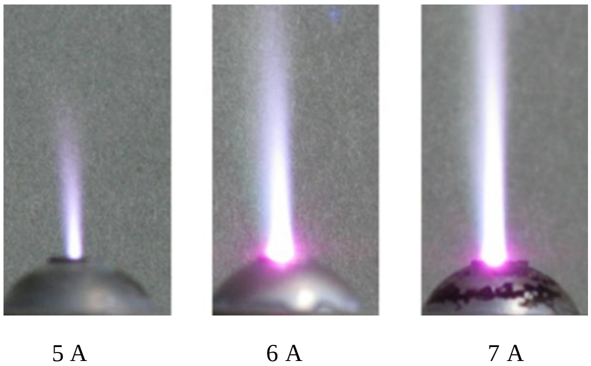

Figure 5. Photographs of water plasma jet according to arc currents.

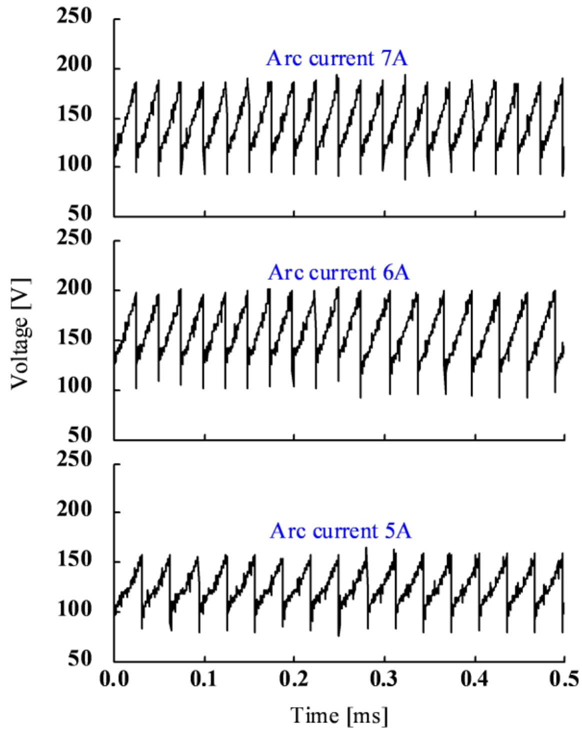

Figure 6. Measured voltage waveforms according to arc currents; at water feeding rate of 248 ml/h.

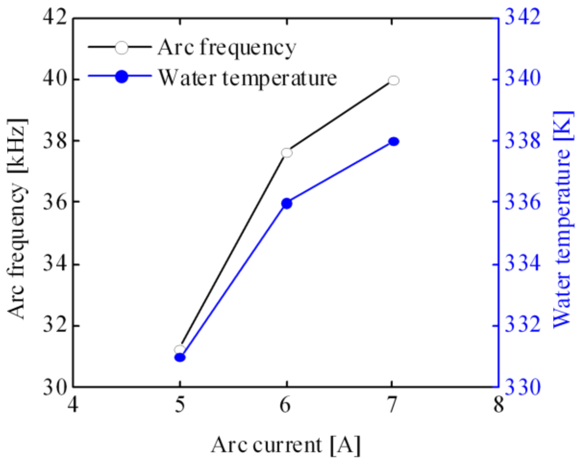

Figure 7. Restrike frequency of the arc discharge and water temperature according to arc currents.

3.3 Effect of water feeding rate

The photographs of the plasma jet at different feeding rates of water are shown in **Fig. 8**. The flame of water plasma becomes smaller at larger feeding rate of water. Therefore, we can consider that the decomposition efficiency of waste treatment has best feeding rate of pollution water in supplied constant power.

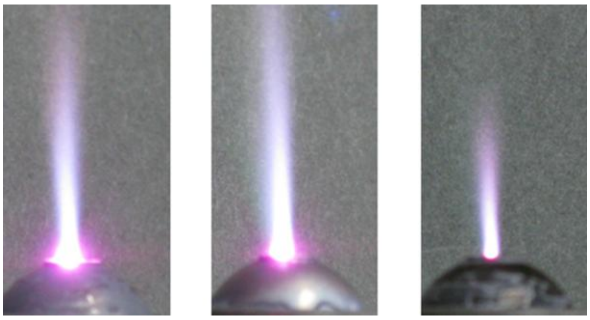

Figure 8. Photographs of water plasma jet according to feeding rates of water.

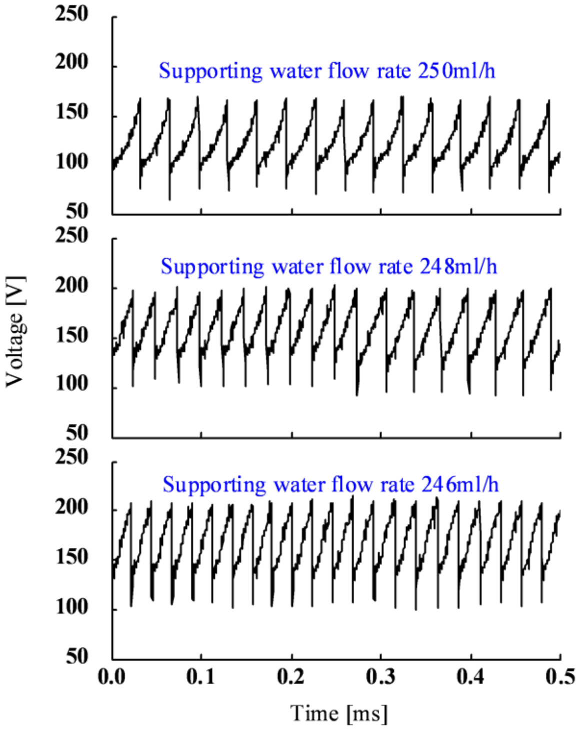

Figure 9. Measured voltage waveforms according to feeding rates of water; at arc current of 7 A.

The voltage waveforms at different feeding rates of water are shown in **Fig. 9**. The water plasma was generated at fixed arc current of 7A. The period of the valley to peak becomes longer at larger feeding rate of water. The effect of water feeding rate on the restrike frequency of the arc discharge and water temperature is shown in **Fig. 10**. The arc frequency decreases with water feeding rate, because the water temperature decreases with the water feeding rate.

The frequency of the arc fluctuation is strongly affected by both the arc current and the water feeding rate. It is because that operating conditions

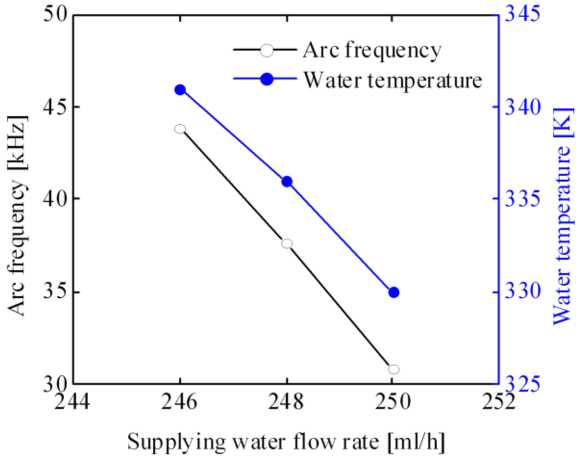

Figure 10. Restrike frequency of arc discharge and water temperature at different feeding rates of water.

of water plasma torch can changes water temperature inside the reservoir. Accordingly different steam generation rate changes gas drag force which has a great effect on arc restrike phenomena. Therefore the high temperature region of the water plasma jet can be controlled by the water temperature in the plasma torch.

4. Conclusion

The arc voltage of DC arc water plasma varied periodically caused by the axial movement of the arc attachment on the anode. The frequency of the arc fluctuation was about several tens of kilohertz. The frequency was strongly influenced by the feeding rate of plasma supporting gas. The high temperature region of the plasma jet controlled by the water temperature in the torch would provide new application of water plasma processing.

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