# Investigation of physical contact between liquid droplet and rotating arc

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**Abstract:** Physical interactions between rotating arc and liquids were visually investigated. A novel design of rotating arc reactor was introduced. The intermittency of rotating arc generated by AC power supply was also examined. Diesel and water were prepared for the reactive and non-reactive liquid, respectively. Different physical interactions were observed depending on the type of the liquids. For the physical interactions, the Leidenfrost effect was focused because the temperature of rotating arc was extremely high.

**Keywords:** Rotating arc, Liquid droplet, Leidenfrost effect, Evaporation, Ignition

## 1. Introduction

Green combustion technologies have been extensively researched due to environmental pollution and international climate change. Plasma-assisted burners have drawn attention to improve abilities of conventional burners in terms of extended flammable limit, emission reduction, and combustion instability [1]. Various kinds of plasma sources were considered to treat gaseous and liquid chemicals. Rotating arc can be utilized for promising applications such as plasma-assisted burner, reformer, and liquid vaporizer because the rotating arc as thermal plasma source generates heat energy through electrical discharge of working gas [2,3]. Technically, arc can be driven by either alternating current (AC) power supply or direct current (DC) power supply, and it is initiated at the gap where the shortest distance between electrode and ground (or anode and cathode). Once the arc is stably formed, it starts rotating due to momentum sources such as magnetic field and swirling motion of discharge gas. The dynamics of the rotating arc is considerably important to determine the performance of the applications. However, to the best of our knowledge, little fundamental research has been done about this topic.

The purpose of the present research was to experimentally investigate and understand physical interactions between rotating arc and liquids. A novel reactor was designed to simulate the condition where a single liquid droplet can physically contact with rotating arc. Discharge gas was air and alternating current power supply was used. Two different types of liquids were prepared. Diesel is a sort of reactive liquids because it could evaporate and ignite with oxygen in air after interacting with rotating arc. Water is a sort of non-reactive liquids because it does not trigger chemical reactions after being evaporated by rotating arc. By using these two liquids, the experiments were intended to visually examine Leidenfrost effect with rotating arc. Considering the temperature of arc itself is extremely high, Leidenfrost effect seems to occur on the liquid surface at the moment when rotating arc physically contacts with the liquids. If so, the liquid droplet might be broken up into tiny size of droplets due to the rapid generation of the vapor from the surface rather than completely being evaporated or consumed via combustion. The phenomenon could be significantly influenced on the performance of rotating arc reactors.

## 2. Experimental approach

Figure 1 describes a typical view of the experiment. The reactor was designed for various purposes. In this work, the investigation of physical interactions between rotating arc and a single liquid droplet was focused in accordance with the research purpose. Alternating current power supply was utilized to generate arc, which can supply electric power up to 6 kW with a frequency of 20 kHz. The shape of electrode had several blades. In addition, the electrode can rotate by the rotating motion of micromotor connected to rotation axis. The shape of ground was a type of a hollow circular cylinder. Air was supply through the gas inlet, and it flowed out with swirl motion. The swirl motion became the momentum of rotating arc. The image presented in Fig. 2 was taken by a high speed CCD camera, X-stream$^{TM}$ XS-3 model with 1000 fps.

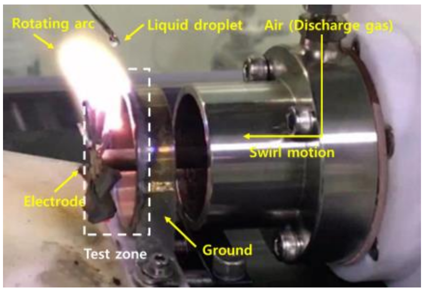


Fig. 1. A typical view of experiment with a novel rotating arc reactor.

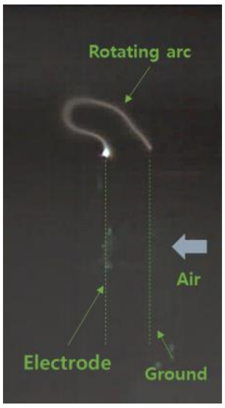


Fig. 2. Side view of the test zone.

## 3. Result summary

Before investigating physical interactions between rotating arc and liquid droplet, the intermittency of the formation of rotating arc was explored. Considering the frequency of the alternating current power supply, it was speculated that the rotating arc had inherently the intermittency in terms of arc initiation and propagation. The intermittency should be examined to properly understand the physical interactions. ICCD camera technique was introduced to capture the AC driven arc characteristic.

Figure 3 presents physical interactions between rotating arc and the droplet of diesel. According to the oscilloscope data, averaged values of applied power, voltage, and current were 167 W, 364 V, and 0.53 A, respectively. The rotating arc and the droplet moved in an opposite direction. During the approaching process of the droplet to the arc, the ignition initially occurred from the closest surface of the droplet to the arc because the temperature of the arc itself was considerably high. In the course of the moment when the droplet physically contacted with the arc, the flame instantaneously covered the whole surface of the droplet. After the droplet passed through the arc, the flame started to detach from the liquid surface. Finally, the flame was extinguished due to the heat loss to atmosphere. As a result, the droplet size was slightly deceased. Even though the arc had enough energy to burn the small droplet off, it failed to completely consume the whole amount of the liquid droplet due to its rotating motion.

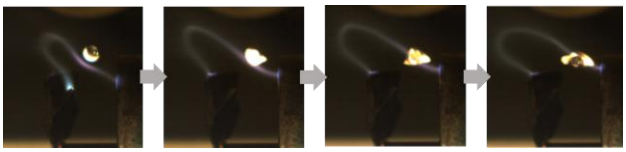

Fig. 3. Physical contact between rotating arc and droplet of diesel.

Water as non-reactive liquid had a different characteristic from the reactive liquid (diesel) because the vapor of water does not further react with oxygen in air. Thus, it needs to be investigated to compare the difference in physical interactions with rotating arc. The droplet tests with water were repeatedly performed in the same way mentioned above. However, no noteworthy phenomena were observed. Although the size of water droplet was roughly similar with that of diesel, the heat energy transferred from the rotating arc during the contact time was not enough to locally vaporize the water droplet because the latent heat of vaporization of water was much larger than that of diesel. Therefore, there were some efforts to modify the test conditions in order to facilitate the investigation of the physical interaction. Fig. 4 represents the test result with water stream and rotating arc. The water stream was rapidly broken off as soon as the rotating arc physically contacted to the stream. Immediately after the splitting of the water stream, tiny droplets split from the main stream was scattered in several directions due to the sudden formation of steam layer in the vicinity of the arc. This phenomenon was similar to the Leidenfrost effect from the physical perspective where a liquid droplet can hover over an extremely hot surface due to the 'repulsive force' resulted from an insulating vapor layer.

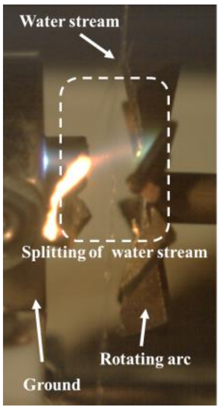


Fig. 4. Leidenfrost effect between rotating arc and water stream.

## 4. References

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[2] D.H. Lee, et. al., Environmental Science and Technology, 47, (2013).
[3] A. Alrashidi, et. al., International Journal of Energy Research, (2017)