Study on the evaporation characterization of dropwise water and DMMP in the plasma atmosphere

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Abstract. Chemical warfare agents are extremely lethal. There has been a lot of related research conducted since World War II. This article takes dropwise water and DMMP (Dimethyl methylphosphonate, Sarin's simulation reagent) as the research objects. By analyzing the data from the infrared band and visible light band, the evaporation features of water and DMMP in different plasma atmospheres (manipulated via setting different voltage and frequency). This work will, to a certain degree, provide experimental references for subsequent research on plasma decontamination of chemical warfare agents.

1. Introduction
Chemical warfare agents (CWA) generally refer to weapons of mass destruction used for war purposes. Typical CWA includes Tabun, Sarin and Soman, etc. It was widely used by fascist countries in World War II. However, after the war, powerful countries such as the United States and the former Soviet Union also began mass production of chemical weapons such as Sarin [1]. Meanwhile, terrorists also used them to make terrorist attacks, for example, the subway explosion planned by the Japanese cult Aum Shinriki in 1995. The decontamination of chemical warfare agents has always been a research hotspot in academia.

Most of the traditional decontamination methods for chemical warfare agents will use specific agents (such as hypochlorite bleach powder pulp and dilute alkali, etc.), that is "wet method" decontamination [2]. It has low efficiency, a great destruction, and poor portability. Besides, some methods are more environmentally friendly, like thermal, photochemical, or chemical catalytic decomposition. Even though less destructive, they usually take at least a few hours and sometimes even hours.

Plasma is a macroscopic electroneutral state of matter with high ionization density. Based on its active physicochemical properties, anti-deicing [3], toxic substance deconsolidation [1], and other research directions can be developed. However, nowadays in the laboratory, the liquid phase or gas chromatography method is commonly used to determine whether the toxic substance has been completely washed out. The general operation procedure is to sample the reaction solution at regular intervals, separate and detect the samples by chromatography, conduct qualitative and quantitative analysis of the simulated reagent by an external standard method, and calculate the degradation efficiency according to the mass concentration of the simulated reagent before and after the reaction [4].

However, it should be noted that such methods require interruption of the reaction process and actual sampling for measurement so that operators are at risk of contamination and toxicity by chemical
warfare agents. Also, precision instruments are vulnerable to contamination by toxic substances. Therefore, given the current situation of contact decontamination monitoring, it is necessary to develop a non-contact, non-blocking method that can simultaneously monitor the plasma disinfection process.

This paper will take the water droplets and DMMP (Dimethyl Methylphosphonate, typical chemical warfare agents sarin simulates reagent) droplets as the research object, explore in different voltage frequency combination incentive of evaporation and differences of different plasma atmosphere, for the use of plasma decontamination of chemical warfare agents monitoring method research to provide certain theoretical basis.

2. Experimental system
The experimental system in this article is shown in Figure 1, which consists of plasma generation system, droplet generation system and data acquisition system. The plasma atmosphere is generated by a periodic plasma exciter (PPA, shown in Figure 2) and an AC power source with adjustable voltage and frequency. The injector is used to generate a precise volume of 0.05ml droplets. The evaporation process is carried out in a fume hood with a set wind speed of 90m³/h. Rely on Nikon D800 (responsible for collecting visible light band data) and FLIR (responsible for collecting infrared band data) to collect image data. The whole experiment was carried out in an environment with a room temperature of 22.4°C and a humidity of 44%.

![Figure 1. Experimental system.](image)
3. Experiment data

3.1. Visual representation
Taking the droplet evaporation process when setting $V_{p-p}=11\,\text{kV}$ and $f=3\,\text{kHz}$ as an example, the evaporation performance of 0.05ml water droplets and 0.05ml DMMP droplets over time in the infrared and visible light bands is shown in Figure 3 (every 2 minutes a frame).

3.2. Time-temperature curve of the center of the droplet
Take the center point of the droplet as the ROI, we collect the time-temperature data of the evaporation process and draw a line chart. The charts under multiple voltage and frequency combinations are shown in Figure 4.
4. Analysis of experimental results

From the visual and curved data, five distinct characteristics can be intuitively seen.

4.1. Division of evaporation stages
Regardless of any combination of voltage and frequency, the evaporation stages of the water droplets are clearly distinguished. In other words, the start point and the endpoint of evaporation can be judged clearly. Because there exists a relatively stable low-temperature section. However, the endpoint of DMMP is not clear for the continuously rising trend of its temperature.

4.2. The average temperature of the evaporating process
The average temperature of the evaporating process is lower for water, that is, more heat is absorbed from the surrounding environment when the water evaporates.

4.3. Initial droplet temperature
The temperature of the water was lower when it was just dropped (T_{ave}(water) = 23.86°C, T_{ave}(DMMP) = 32.48°C). This value is closer to room temperature (22.4°C).

4.4. Infrared image characteristics
As far as infrared waveband data is concerned, the contour of water droplets can be roughly distinguished by a larger temperature gradient. Nevertheless, this characteristic is vague for a DMMP droplet. That is to say, the image characteristics of the former evaporation end are easier to be recognized.
4.5. Visible light image characteristics

In terms of visible light waveband data, the evaporation process of water droplets will not affect the subsequent generation of plasma, while the evaporation process of DMMP will break the regeneration of the plasma atmosphere. Intuitively, the plasma array generated in the later stage of DMMP evaporation is destroyed and weakened. But for water, that is still in a good condition.

5. Conclusion

In summary, whether it is by visual data or time-temperature curves, water droplets and DMMP droplets have huge differences during and after the evaporation process. Such characteristics can be used to detect chemical warfare agents in real-time or monitor during the plasma decontamination process in the future.

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