

Experimental study on evaporation characteristics of a hydrogen peroxide droplet at elevated temperature

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Abstract. In this study, evaporation characteristics of a hydrogen peroxide droplet, 90% purity, was experimentally investigated at elevated temperature (between 400 and 800 °C) and atmospheric pressure under normal gravity. Elevated temperature atmosphere was provided by electric furnace inside the chamber. The range of a droplet size was 1.1 mm to 1.3 mm. The evaporation process of a droplet was recorded by high speed CCD camera. As analysing the image extracted from the camera using the program, evaporation rate of a single droplet was calculated at each ambient temperature. After thermal expansion period, evaporation rate of a hydrogen peroxide droplet followed d²-law but thermal expansion period didn't clearly separate at 400 °C. The evaporation rate increased with increase in ambient temperature. Also thermal decomposition of hydrogen peroxide increased at high temperature.

1. Introduction

In the recent year, hydrogen peroxide has received attention to monopropellant as well as oxidizer in the space rocket system because of lower toxicity than conventional propellants. That's why lots of researchers have investigated the hydrogen peroxide to apply in space thruster system [1]. Hydrogen peroxide has decomposition process under normal condition. However the decomposition goes very slowly so catalysts have been used to promote. When hydrogen peroxide of high concentration was decomposed, it can be described by a single step reaction of the exothermic process as (1) where Q is generated heat [2]. But this single step reaction could not spontaneously occur at low temperature except for adding a catalyst and high temperature.



Many previous researchers have studied on hydrogen peroxide for using monopropellant but researches related to evaporation characteristics of a hydrogen peroxide droplet are insufficient so evaporation rate of hydrogen peroxide has used as speculated value based on theoretical equation [3, 4].

Evaporation research of a liquid droplet at high temperature is one of basic studies in spray combustion for applying to various fields such as industrial furnace, incinerator, internal engine, etc. What evaporation characteristics of a single droplet investigate is essential for understanding complicated process of spray evaporation and combustion [5].



This research is experimental study on evaporation characteristics of a hydrogen peroxide droplet which is a basic study for applying to theoretical equation in numerical simulation and spray combustion researches.

2. Experimental apparatus

1.1. Experiment procedure

Fig. 1 is the schematic diagram of experimental apparatus that has been used in previous researches [5, 6, 7]. As using the temperature controller, atmospheric temperature inside electric furnace was uniformly increased. The temperature variation inside the furnace was about $\pm 5^{\circ}\text{C}$ at targeted temperature. When the electric furnace reached at targeted temperature, a droplet was suspended at the tip of quartz fiber using an injector. The diameter of injector hole is very small size ($100\text{ }\mu\text{m}$). The diameter of quartz fiber is 0.125 mm and it has spherical shape bead (0.25 mm) at the tip. The size of suspended droplet was from 1.1 mm to 1.3 mm . When a droplet suspended at the tip of quartz fiber, it existed with a side effect. Heat conduction between quartz fiber and a droplet happened during evaporation process of a droplet. This effect was experimentally and theoretically investigated from previous study [8]. Heat conduction through quartz fiber enhanced evaporation of a droplet and this effect increased when thickness of a fiber was thicker and lower ambient temperature. In this study, used quartz fiber was thin in high temperature environment so this effect can be negligible.

The electric furnace fell down to downstairs along the two guide bars as using the lever after a droplet was suspended at the tip of quartz fiber. When the furnace arrived at the bottom, a droplet started to vaporize and the process of droplet evaporation was recorded by high speed camera (operating at a rate of 500 frames per second) through the quartz window. Acquired images were analyzed for calculation of droplet size using the program based on Visual Basic which was validated from previous study [7].

Table 1. Thermochemical properties of hydrogen peroxide

Density (g/cm^3)	1.41
Boiling point ($^{\circ}\text{C}$)	141
Specific heat ($\text{J}/\text{g}\cdot\text{K}$)	2.619 (liquid)
Heat of Vaporization (kJ/g)	1.517
Viscosity (cP)	1.245
Vapor pressure at 20°C (kPa)	0.2

1.2. Fuel

Used fuel was hydrogen peroxide (90% purity) made by HABO chemical. For protecting the decomposition, fuel was storage in the fridge at 5°C . Table I is the thermochemical properties of hydrogen peroxide. It has characteristics of strong surface tension and hard to vaporize because of hydrogen bond comparing with conventional fuel.

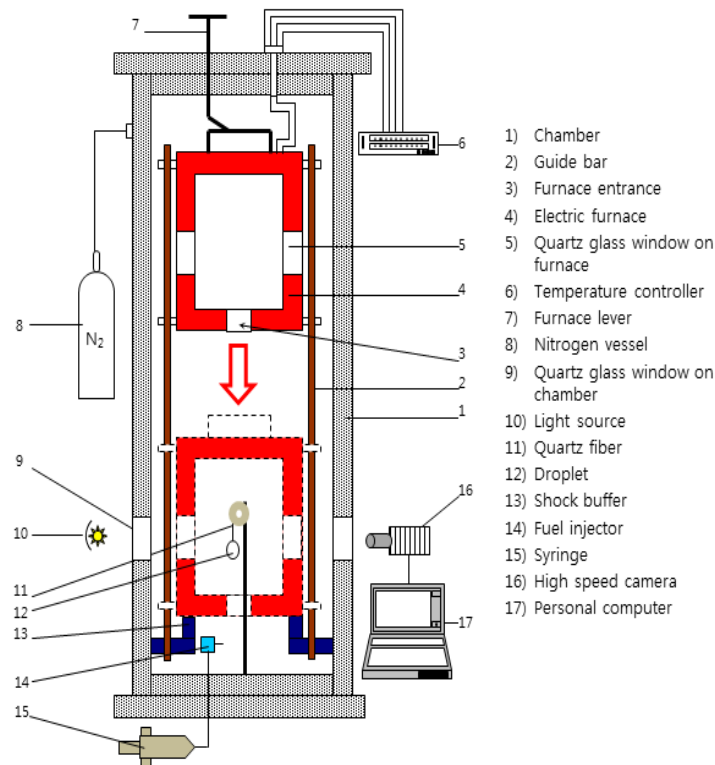


Figure 1. Schematic diagram of experimental setup

3. Results and discussion

Fig. 2 is the normalized temporal variation of squared diameter of a droplet. At relatively high temperature, the diameter of a droplet was increased because of thermal expansion. The thermal expansion happened when the amount of evaporation of liquid fuel was relatively lower than reduced density resulted from increasing ambient temperature. Density is mass divided by volume so droplet size related to volume is increased. The thermal expansion effect was larger in case of higher ambient temperature. Table II is normalized maximum droplet size pass a thermal expansion process at each temperature. At 400°C, a droplet slightly increased a diameter. The droplet diameter increased as ambient temperature was higher. From this result, the effect of reducing density was dominant comparing with an amount of liquid evaporation in thermal expansion period. After this period, a balance between thermal expansion and liquid evaporation determined a droplet size. A balance made a droplet reached a quasi-steady state. In this period, the temperature of a droplet was uniform but a size of a droplet was shrunk because of evaporation. But quasi-steady state was assumed that a droplet had uniform temperature and same size in infinitesimal time. At high temperature, these periods easily distinguished but it was hard to separate between thermal expansion and quasi-steady state at low ambient temperature. At 400°C, a droplet was slowly decreased at beginning evaporation process and then it was linearly decreased. In this temperature, thermal expansion didn't almost happen because the effect of volume increase was not larger than an amount of evaporation. At linear evaporation period, a droplet followed the d^2 -law expressed as (2) where d_0 is the initial diameter and C_v is the evaporation rate [9]. The linear slopes in fig. 2 are evaporation rates at each ambient temperature. The best slope line was estimated using the least square method.

$$d^2 = d_o^2 - C_v t \quad (2)$$

Each evaporation rate of a droplet is shown as Table III at elevated temperature. In case of higher ambient temperature, evaporation rate increased. Especially, the rate of increase sharply grew from 600°C to 700°C.

Fig. 3 is temporal variation of droplet images at each ambient temperature. At 400°C, a droplet was verified not to almost expand. In case ambient temperature was higher, the thermal expansion effect was bigger and a droplet was not transparent. During the evaporation process, small water vapors boiled inside a droplet because of different boiling temperature comparing with hydrogen peroxide. Due to thermal decomposition, an amount of vapors of water and oxygen increased and then they blocked the back light that's why droplet image changed to dark. At high temperature, thermal decomposition of hydrogen peroxide more actively happened. As soon as the droplet started evaporation process, thermal decomposition of hydrogen peroxide actively occurred so center image of a droplet was fast opaque.

Fig.4 is the micro explosion phenomenon inside a droplet. The micro explosion phenomenon makes a fuel droplet to smaller particles so a droplet can be well atomized. The combustion of atomized droplet is similar to complete combustion that's why this improves combustion efficiency and reduces air pollutant emission [10, 11]. The major cause of micro explosion is the sudden explosion of water droplets which is superheated inside a droplet. Beyond 700°C of ambient temperature, micro explosion phenomenon occurred. The red boxes in fig.4 show that small droplet particle came out from an original droplet. As lots of small droplets went out consistently during evaporation process, a droplet didn't have perfect spherical shape. This phenomenon could be observed at high ambient temperature which was related to thermal decomposition of hydrogen peroxide. Thermal decomposition actively occurred at higher temperature and then water and oxygen gases were produced by single step reaction with heat. Through continuous thermal decomposition reaction, lots of water were produced and superheated. Because the large amount of superheated water was explosive, micro explosion happened in a droplet.

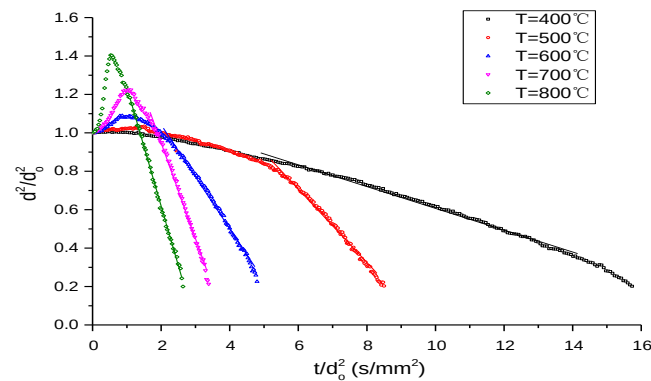


Figure 2. Normalized temporal variation of the diameter squared divided by initial diameter squared of a droplet

Table 2. Normalized maximum diameter during thermal expansion period

Ambient temperature (°C)	400	500	600	700	800
Maximum droplet diameter (d^2/d_o^2)	1.007	1.034	1.090	1.225	1.404

Table 3.Evaporation rate of a droplet in linear decrease period

Ambient temperature (°C)	400	500	600	700	800
Evaporation rate	0.056	0.19	0.27	0.49	0.61

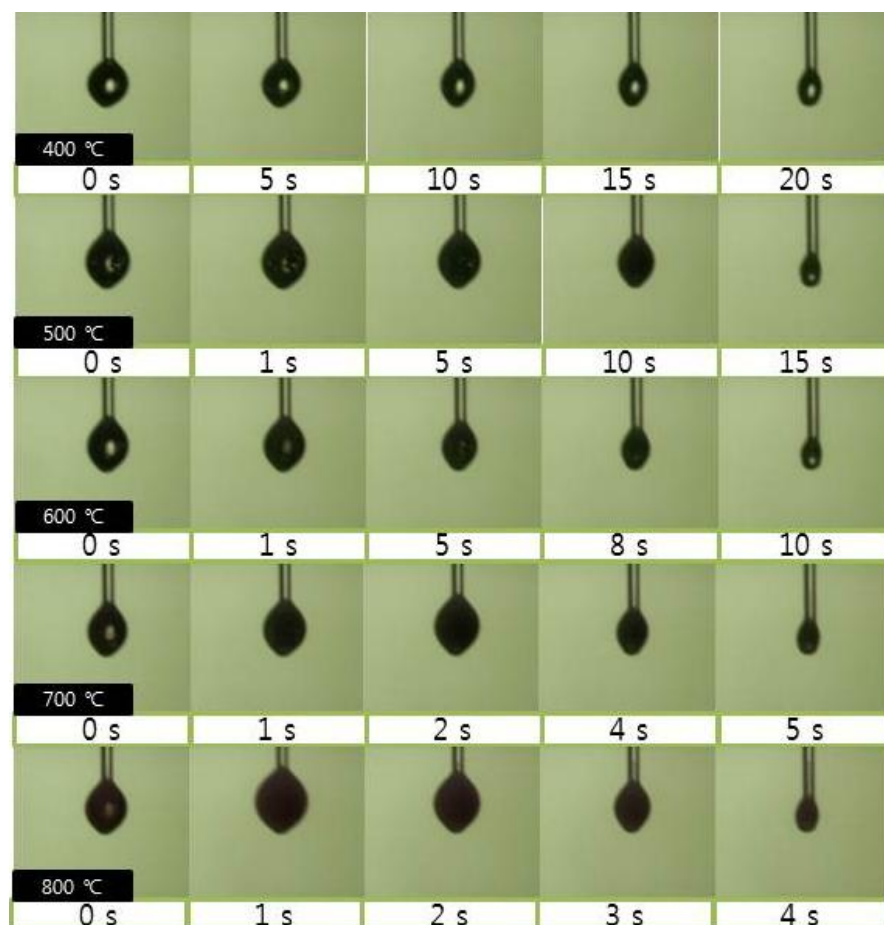


Figure 3.Temporal variation of droplet size at each temperature



Figure 4.Micro explosion phenomenon of a droplet at 800°C

4. Conclusion

This study was focus on the evaporation characteristics of a hydrogen peroxide droplet at elevated temperature. The followings are summarized results.

- 1) A droplet of hydrogen peroxide follows d2-law after thermal expansion period.
- 2) The evaporation rate of a hydrogen peroxide droplet increases along increase in ambient temperature.
- 3) In case of higher ambient temperature, thermal decomposition actively is promoted and water vapor and oxygen gas inside a droplet increases.
- 4) Micro explosion phenomenon occurs during evaporation process beyond 700 °C of ambient temperature.

After this research, other concentrations of hydrogen peroxide will compare with experimental and theoretical results.

5. References

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