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# Microgravity experiments of fuel droplet evaporation in sub- and supercritical environments

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**Abstract**

Droplet evaporation in sub- and supercritical environments has been studied experimentally under microgravity conditions. A single suspended droplet of n-hexadecane was employed for the experiments. The initial droplet diameter was 0.4 mm. A pair of alumina/silica fibers of 7 μm in diameter was applied to suspend a droplet. The ambient pressure was varied in the range of 1.0–3.0 MPa, and the ambient temperature was set at 773 K. Sequential backlit images of an evaporating droplet were recorded using a high-speed digital video camera. Temporal variations in the droplet diameter were measured using a self-made computer-aided image analyzer. Microgravity conditions were produced by a 50-m drop tower. Temporal variations in the droplet diameter were successfully obtained for droplet evaporations in the supercritical environments. The normalized droplet lifetime increased with the ambient pressure. The evaporation rate constant increased with the ambient pressure, reached the maximum value at an ambient pressure slightly above the critical pressure of the fuel, and then decreased. The initial heat-up period linearly increased with the ambient pressure, reached the maximum value at an ambient pressure of 2.0 MPa, and then decreased. The ratio of the initial heat-up period to droplet lifetime increased with the ambient pressure, reached the maximum value of about 0.6 at an ambient pressure of 2.0 MPa, and then decreased. The droplet evaporation lifetime increased with the ambient pressure at subcritical ambient pressures even though the evaporation rate constant increased because the increase in the initial heat-up period overtook the decrease in the quasi-steady evaporation period. It was found that, in the case of fuels with a high critical temperature, the initial heat-up period determines the ambient pressure dependence of the droplet evaporation lifetime in the environments around the critical point of the fuel.


*Keywords:* Droplet; Evaporation; Supercritical environment; Microgravity experiment; Spray combustion

## 1. Introduction

Spray combustion is widely applied to combustors operated at high pressures, such as diesel

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engines and jet engines. The droplet evaporation lifetime is one of the important parameters in the design of spray combustors, because the evaporation lifetime of the largest droplet in a spray determines the residence time required for the complete droplet evaporation in the combustor. Many experimental studies have been carried out to examine droplet evaporation [1–15]. Most of them employed a suspended droplet or a porous sphere around or more than 1 mm in diameter as an experimental object. However, fuel droplets in spray combustors are so fine that the influences of both natural and forced convections on droplet evaporation are negligible even in high-pressure environments. Evaporation experiments of a droplet in a non-convective field [16-20] are suitable to obtain useful data for estimation of droplet evaporation in spray combustion and verification of theoretical and numerical models [21–31]. In previous works [17, 18], two authors investigated n-heptane droplet evaporation at high temperatures and high pressures using microgravity conditions in order to suppress natural convection, which becomes strong with an increase in the ambient pressure and temperature. The observations of droplet evaporation were carried out with widely varying ambient temperature and pressure. However, temporal variations in the droplet diameter were obtained for only subcritical environments, which indicates the ambient temperature and/or ambient pressure are/is below the critical value of the fuel.

Droplet evaporation in supercritical environment is very complex phenomenon because fuel properties change drastically around the critical point. Therefore, experimental data are required to verify the theoretical and numerical models of droplet evaporation in supercritical environments. However, no such experimental data have been obtained under microgravity conditions because it is difficult to prepare adequate experimental apparatus sufficiently compact to fit the microgravity setup such as a drop capsule. One of the difficulties is the observation of a droplet. Typical experimental apparatus for investigation of droplet evaporation at high pressures is equipped with a high-temperature chamber in a high-pressure chamber. The temperature difference between the high-temperature chamber and the high-pressure chamber causes heat haze between the observation window glasses of both chambers. This heat haze distorts the droplet image. To obtain clear images of a droplet evaporating in a supercritical environment, the gap between the observation window glasses of both chambers was minimized, and a fuel with a low critical pressure, namely n-hexadecane, was employed in this work. *n*-hexadecane is low-volatility fuel. Since microgravity duration produced by a drop tower is limited, the initial droplet diameter was reduced to about half of that in the former work. The droplet suspension system was improved to suppress the thermal influence of a droplet suspender on a small droplet.

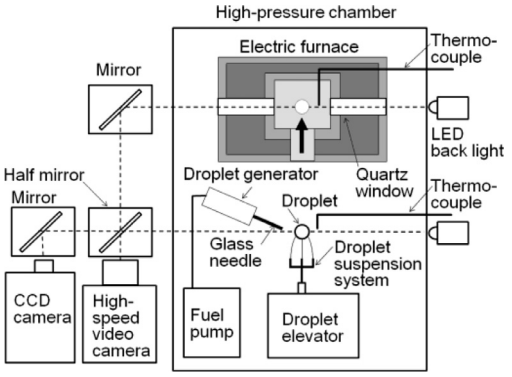


Fig. 1. Experimental apparatus.

The purpose of this work is to obtain temporal variations in the droplet diameter for droplet evaporation in stagnant sub- and supercritical environments. The obtained data will be used for evaluation of the numerical models and simulation results of the droplet evaporation under various ambient conditions in the future. Microgravity experiments were performed with a single suspended droplet. The droplet evaporation lifetime and evaporation rate constant were measured from the temporal variations in the droplet diameter.

## 2. Experimental apparatus and procedure

Evaporation experiments were performed within a high-pressure chamber (inner diameter: 100 mm; inner height: 229 mm). Figure 1 shows the experimental apparatus, which consists of the high-pressure chamber, a digital high-speed video camera (Phantom Miro 3), a CCD video camera, mirrors, LED backlights, and a sequencer. The high-pressure chamber included an electric furnace, a droplet generator, a piezo pump, a droplet elevator, and two K-type thermocouples. The high-pressure chamber can be pressurized up to 5 MPa. Pressurized nitrogen is fed from a cylinder into the high-pressure chamber to increase the pressure in the chamber and to prevent self-ignition of the fuel. The electric furnace (inner diameter: 30 mm; inner height: 30 mm) produces a stagnant high-temperature field in the high-pressure chamber. A droplet is generated outside the electric furnace and inserted into the electric furnace through the slit at the bottom of the electric furnace by the droplet elevator just before observation. The distance from the droplet generation position to the test position in the electric furnace is 60 mm. Liquid fuel is supplied from a fuel reservoir to the droplet generator by the piezo pump in the high-pressure chamber.