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微小重力環境における粉塵爆発リスク評価を目指して

Risk assessment of dust explosions in a microgravity environment

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1. Introduction

Combustible dust particles such as organic materials, coal, and metals in the powder handling processes poses a dust explosion that a flame propagates through the dust clouds. Such dust explosions are affected by the gravity level because the explosions can occur when combustible dust particles are dispersed in the air. For the lunar and planetary exploration activities, the risk of dust cloud explosions must be discussed as a crucial safety concern, because of reduction of the settling effect of particles in microgravity. Therefore, it becomes an utmost necessity to understand the combustion phenomenon of the dust clouds in microgravity conditions to establish various policies and precautionary measures to prevent such accidents in the space environment. Previous studies by the microgravity experiments such as drop towers, parabolic flights, and sounding rockets have almost exclusively focused on the measurement of the burning velocity of dust clouds[1-7]. Despite decades of research, this issue on the burning velocity of dust clouds continues to be debated because of the uncertainty of accurate and reproducible dust concentration measurement. A more systematic analysis is required for the flame-particle interaction in dust explosions because the quantitative measurement of concentration is a critical aspect of understanding dust explosions. One of the major aims of this work is to develop more sophisticated methods for the estimation of burning velocity and concentration of dust clouds in microgravity environments. Our second objective is to understand the effect of particle concentration on the flame speed comparing the experimental results and numerical predictions for safety protocols for dust explosions.

2. Dust Explosions in Microgravity

In the present study, aluminum that the most widely used not only in process industries but also as fuel for rocket propulsion because of its favorable combustion properties and efficiency were used. The microgravity experiments of aluminum powder with a mean particle diameter of 20 μm were conducted using a 2.5 second drop tower. The experimental apparatus consisting of a combustion tube, a powder dispersion system, an ignition system, and a high-speed visualization system to simultaneously measure the behaviors of flame and particle was developed to conduct the microgravity experiments as seen in Fig. 1. The aluminum powders were dispersed into the 1.176 L volume combustion

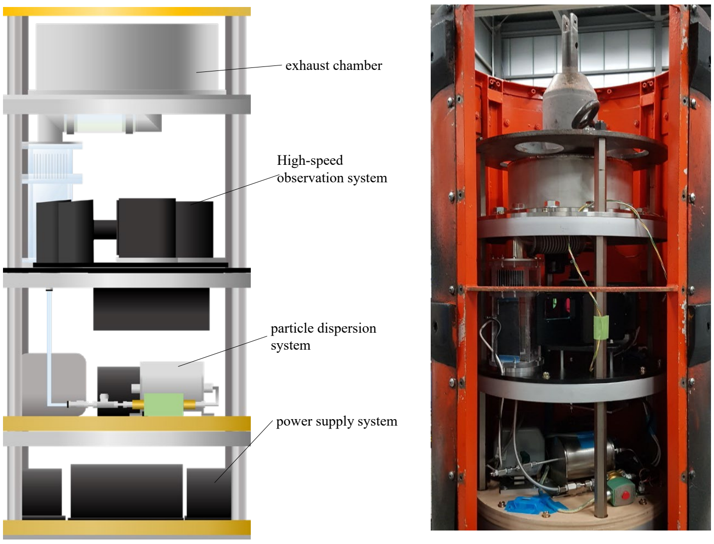
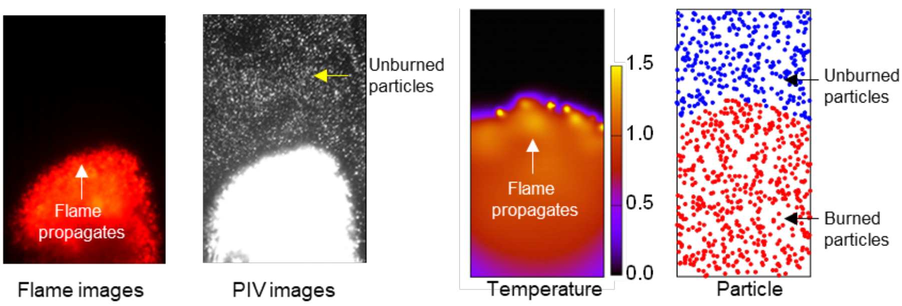


Fig. 1 Experimental apparatus for drop tower experiments [8].

tube by using pressurized air of 15 kPa and the dispersed powders in the air were ignited by the ignition system after the start of microgravity. The behaviors of flame and particle were recorded by high-speed observation system with the continuous wave laser output power of 5 W at a wavelength of 532 nm and the motion of particle was analyzed by carrying out particle image velocimetry. Further details of the apparatus and procedure can be found in previous work[8)].

The experimental results show that the high-speed turbulent flow during the dispersing process observed from the microgravity experiments and the speed also increased as time goes by. After the dispersion process the flow speed in the tube decreased gradually. The spherical flame in aluminum-air mixtures propagated to unburned particles as shown in Fig. 2 (a). The present experiment confirmed the findings that the flame speed increased with a decrease in the mean particle distance corresponds to dust concentration. Such result demonstrates that the flame speed depends on the dust concentration. A further novel finding is that the particles in front of the flame are moved by the flame expansion during the dust explosion. Numerical simulations on the flame propagation through dust clouds of aluminum particle were also conducted[9)]. Figure 2 (b) shows that the temperature distribution of propagating flame for random particle configurations. The prediction from the model that the temperature distribution is implemented using Green's function in the heat conduction equation compared to experimental data. A similar conclusion that the increasing trend of the speed with the decrease in the mean particle distance was reached by the numerical simulations. Future investigations on the mechanism of flame propagation during dust explosions are necessary to validate the kinds of conclusions that can be drawn from this study.



(a) Experiments (b) Simulations [9]

Fig. 2 Experimental and numerical flame images.

3. Conclusion

For risk assessment of dust explosions in microgravity environments, in the present study, the effect of particle concentration on the flame speed was investigated experimentally and numerically. The microgravity experimental apparatus for measurement both the flame propagation and dust concentration was developed. The drop tower tests on the dust explosion of 20 μm aluminum powder were conducted. The experimental results demonstrated that the flame speed increased with the decrease in the mean particle distance corresponds to dust concentration. The dependency of the dust concentration on the flame speed from experimental data was found to agree with numerical simulation. Future studies could fruitfully explore this issue further by long-duration microgravity tests such as parabolic flights, sounding rockets.

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