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ガスジェット浮遊法による溶融金属酸化物の熱物性値測定法の確立：静的形状からの表面張力同定

Measurement framework for thermophysical properties of molten metal oxides by aerodynamic levitation: Identification procedure of surface tension from static droplet shape

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1. Introduction

For sustainable manned activities on the moon, manufacturing with lunar regolith is essential [1,2]. Especially, the melting and solidification process is necessary for the exterior walls so that they can survive in the severe lunar environment. For this purpose, preliminary numerical simulations play significant roles in the design of efficient manufacturing processes. Although the main components of the lunar regolith are metal oxides, however, the thermophysical properties of molten metal oxides have been measured for only a few materials. Therefore, the measurements of the thermophysical properties of molten metal oxides are an important task. For such measurements, aerodynamic levitation (ADL) is regarded as a suitable method, but there is an uncertainty problem because a part of the droplet is hidden by the nozzle. In this study, we propose a method to identify the thermophysical properties of droplets by minimizing the effect of droplet hiding with a physical model constructed to add gas-jet pressure to the Young-Laplace equation and a data assimilation method with a Physics-Informed Neural Networks (PINN) [3].

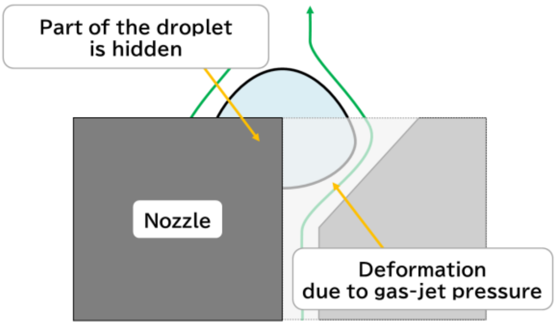


Fig.1 . Things of ADL that need to be improved.

2. Identification of surface tension

2.1. Method of identifying physical properties by data assimilation

Even if a part of the droplet is hidden by the nozzle, the droplet shape of the observable parts is affected by the surface tension. In this study, the surface tension is identified from a part of droplet shapes by the method shown in **Fig.2**. A mathematical model is constructed assuming that the levitated droplet is under equilibrium where gravity, Laplace pressure, and gas-jet pressure are balanced. Using this model, the equilibrium droplet shape can be predicted from a given surface tension. The predicted surface shape is compared with the measured droplet shape, then the error between them is evaluated. The surface tension of a droplet is determined so that the error is minimized.

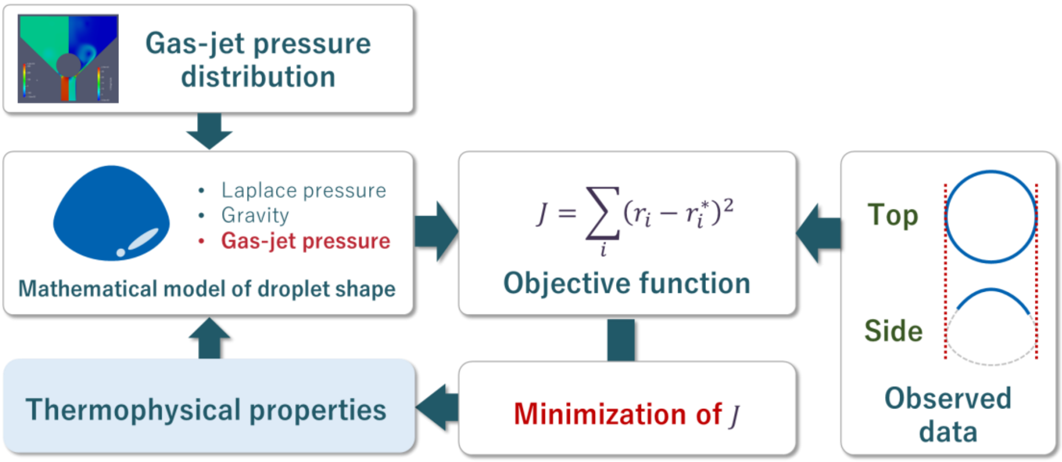


Fig.2 . Proposed method for physical property identification method by data assimilation.

2.2. Mathematical model of droplet shape

The droplet is assumed to be axisymmetric with respect to the direction of gravity. The following differential equations are obtained for the static shape of a droplet using the axisymmetric coordinate system R, φ, Z as

$$K - \frac{2}{\Gamma} - Bo(1 - Z) + BoP_s C_p(\varphi) = 0, \tag{1a}$$

$$K = \frac{R^2 + 2R'^2 - RR''}{(R^2 + R'^2)^{\frac{3}{2}}} + \frac{R + R'\tan(\varphi)}{R(R^2 + R'^2)^{\frac{1}{2}}}, \tag{1b}$$

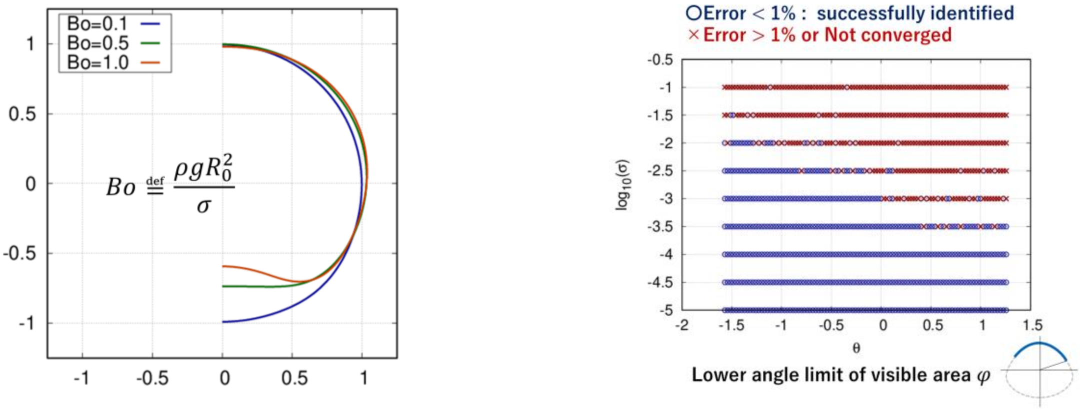
where equation (1a) is the modified Young-Laplace equation which involves the gas-jet pressure, Laplace pressure, and gravity. Equation (1b) is a curvature in a spherical coordinate system. $C_p(\varphi)$ gas-jet pressure distribution normalized by the stagnation pressure, ρ is density, and g is the acceleration of gravity. The equations are nondimensionalized with the length scale as the radius of the sphere R_0 and the pressure scale as $\rho g R_0$. The dimensionless numbers used in the model are as below:

$$R = \frac{r}{R_0}, Z = \frac{z}{R_0}, Bo = \frac{\rho g R_0^2}{\sigma}, P_s = \frac{p_s}{\rho g R_0}, \Gamma = \frac{R_s}{R_0}, \tag{2}$$

where σ is surface tension, p_s is stagnation pressure of gas-jet pressure distribution, and R_s is the radius of curvature at the droplet top surface, respectively.

3. Results

Fig.3(a) shows the droplet shape calculated by the PINN for three different values of Bo=0.1,0.5,1.0. The larger the Bond number, the smaller the relative contribution of surface tension, and the larger droplet deformation are recognized. In this study, the validity of the proposed data assimilation method was confirmed by the *twin experiments* whose results are shown in **Fig.3(b)**. When the noise is sufficiently small, the Bond number can be identified even if the only small top region of the droplet is observed. However, as the noise increases, the identification accuracy decreases if the droplet's bottom cannot be observed.



(a) (b)

Fig.3. (a) Calculated droplet shapes,
(b) Results on whether the surface tension is reconstructed from the observed data.

Acknowledgments

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