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Generation of a Strong Core-Centering Force in a Submillimeter Compound Droplet System*

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Abstract

By amplitude-modulating the driving voltage of an acoustic levitating apparatus, a strong core centering force can be generated in a submillimeter compound droplet system suspended by the radiation pressure in a gaseous medium. Depending on the acoustic characteristics of the droplet system, it has been found that the technique can be utilized advantageously in the multiple-layer coating of an inertial confinement fusion pellet.

Introduction

One of the important areas of research pertinent to the fabrication physics of inertial confinement fusion targets involves the investigation of various physical mechanisms that generate bubble-centering forces during the formation stage of fusion pellets. Theoretically, the strength of this force is proportional to the frequency of the normal mode oscillation of the compound-droplet system[1]. This frequency is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{\sigma\ell(\ell+1)(\ell-1)(\ell+2)\left[\varepsilon^{\ell+\frac{1}{2}} - \varepsilon^{-(\ell+\frac{1}{2})}\right]}{\rho R_o^3\left[(\ell+1)\,\varepsilon^{\ell+\frac{1}{2}} + \ell\,\varepsilon^{-(\ell+\frac{1}{2})}\right]}}\,, \tag{1}$$

for a rigid-cored compound-droplet system of an inviscid fluid. σ and ρ are the surface tension and density of the fluid, respectively. R_o is the radius of the compound drop, ε is the ratio of R_o to the radius of the core and ℓ is any positive integer with the fundamental frequency corresponding to $\ell = 2$. In Fig. 1, Eq. (1) is plotted for the fundamental oscillation frequency ($\ell = 2$) versus R_o. It is interesting to note that, for the two core sizes chosen in the figure, there is an optimal R_o at which the oscillation frequency reaches a maximum. This value of R_o can be regarded as the most efficient radius of the compound-droplet system to generate the core-centering force.

It is most convenient to generate and study this core-centering force using an acoustically-levitated submillimeter compound-droplet system. First, the oscillation can be excited easily by amplitude modulation of the carrier voltage of an acoustic levitating apparatus at the appropriate normal mode frequency of the compound droplet system. Second, for a submillimeter compound-droplet system, the core-centering force is very strong indeed. In comparison, the force is only barely observable for drop systems 5 mm or larger.

Experimental Apparatus

An acoustic apparatus has been specifically developed to handle samples of submillimeter sizes in a gaseous medium. This apparatus consists of an acoustic levitation device, deployment devices for small liquid and solid samples, heat sources for sample heat treatment, cold gas cooling system, acoustic alignment devices and data acquisition instrumentation. The levitation device includes a spherical aluminum dish 12" in diameter and 0.6" in thickness, 130 pieces of PZT transducers attached to the back side

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of the dish and spherical concave reflector situated in the vicinity of the center of curvature of the dish. In Fig. 2, the underside of the focusing radiator is shown. In operation, the transducers are driven in phase at one of the resonant frequencies of the radiator. Figure 3 gives the top view of the hemispherical dish. At the center is the reflector for the production of the levitating force. A liquid sample atomizer is shown at the left. In Fig. 4, this device is shown in greater detail. It consists of an acoustic stepped-horn and two PZT transducers pre-stressed to 5000 psi for high power operation. It is supported by a knife edge at the step. A liquid drop placed at the tip of the horn can be transported to the levitating position through an atomization process. The focusing radiator levitating device operates at 75, 105 and 163 kHz, respectively. It has been demonstrated that a sample with a specific gravity as large as 19.3 can be levitated in this apparatus. The lateral positional wandering of the sample in the force well is estimated at less than 5% of the dimension of the sample size used.

Compound Droplet System

To create a compound droplet system, a solid sphere is first positioned in the acoustic field at the tip of a vacuum chuck and allowed to drift into the force region upon vacuum release. Liquid material is deployed by first atomizing the material into a fine mist in the vicinity of the force well. The mist is driven by the acoustic force, depositing it onto the surface of the sphere forming a compound droplet system. A typical droplet system has a dimension of about 250 μm diameter for the core and 100 μm thick shell for the liquid layer.

Usually, a compound droplet formed in this manner is not designed to be neutrally buoyant. The gravitational force will manifest itself in two ways: 1. Depending on the relative specific gravity between the core and the fluid, the core will be off-centered, float to the top or sink to the bottom of the liquid shell, and 2. The gravity will deform the droplet to an approximately oval shape (Fig. 5). The second effect could be minimized significantly by increasing the surface tension of the fluid and/or reducing the size of the droplet. It has been observed that the percentage deformation between the two axes is less than 5% for a pure water droplet of typical 500 μm in size. The first effect, on the other hand, is omnipresent, as long as the experiment is performed terrestrially in a one-g environment.

Core-centering Force

The core-centering force has been observed in a compound-drop system of 1 cm or larger in a neutral buoyancy tank, where three liquids of comparable specific gravity are present. The core-centering force, in this case, is rather weak because of the size of the drop and the particular set of boundary conditions involved. In this report, we will present results of a strong core-centering force generated acoustically in a submillimeter compound droplet system suspended by the radiation pressure in a gaseous medium.

To generate such a core-centering force, the liquid shell is set into oscillation at one of its natural normal modes. To accomplish this, an amplitude modulation at appropriate frequency is applied to the carrier driving voltage of the focusing radiator levitating apparatus. When the frequency of the amplitude modulation is tuned into the natural oscillation frequency of the compound droplet system, a large amplitude oscillation of the liquid shell is produced driving the core to the center of the system in a fraction of a second. For a typical sized droplet used in the experiment, a modulating frequency between 500 to 1000 Hz is required. Using a water-coated glass-microballoon system, it can be further verified that this is a very strong force indeed in view of the fact that the ratio of specific gravities between the water and the core is approximately five. In Fig. 6, a glass microballoon coated with a layer of water is shown to be centered by this force.

An experimental technique to quantify this force has been devised. A promising method is to generate a secondary oscillation of the core in the presence of the core-centering force. From the frequency of the core oscillation, a force constant k can be measured, thus the core-centering force can be obtained from $f = -kx$, where x is the displacement of the core from the center position in the presence of the core-centering force.

Summary and Concluding Remarks

In summary, we have demonstrated an acoustic technique for generation of a strong core-center force for a submillimeter compound-droplet system. Centering forces of this general nature are important in understanding the physics of, for instance, the formation of glass pellets. The application of this kind of force, for example, can be very advantageous in the multiple-layer coating of an inertial confinement fusion pellet[3].

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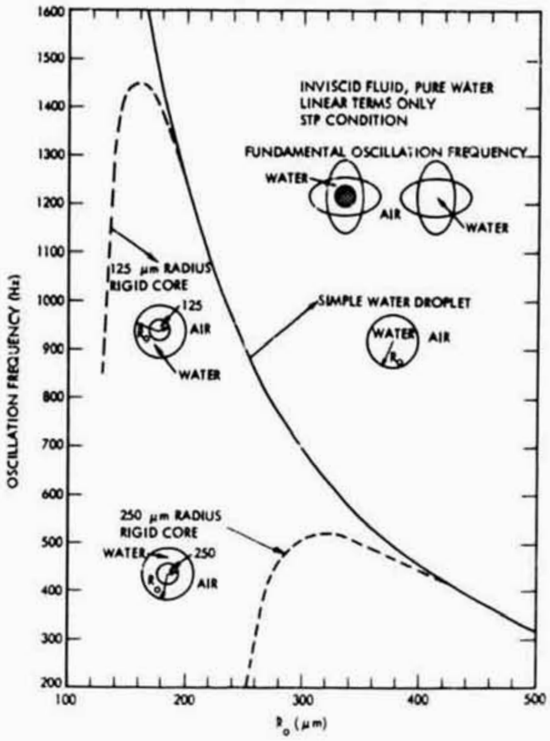

Figure 1. Frequency of normal mode oscillation as a function of the radius of a compound droplet system. The core is rigid and $\ell = 2$.

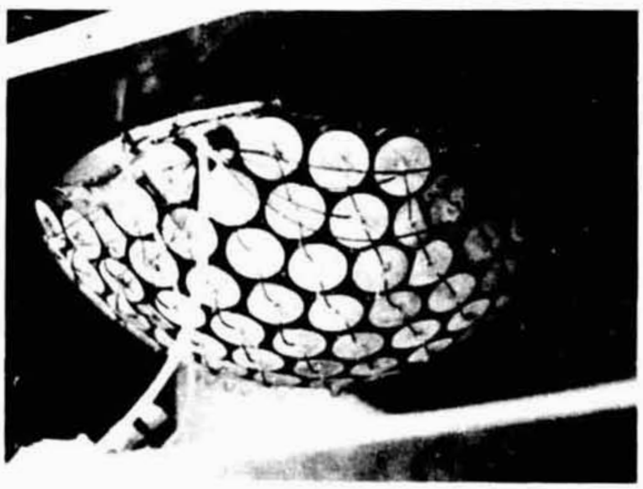

Figure 2. The underside of the focusing radiator acoustic levitation apparatus.

Figure 3. The top view of the focusing radiator acoustic levitatior apparatus. The reflector is situated at the vicinity of the focal point. The liquid sample atomizer is at the left.

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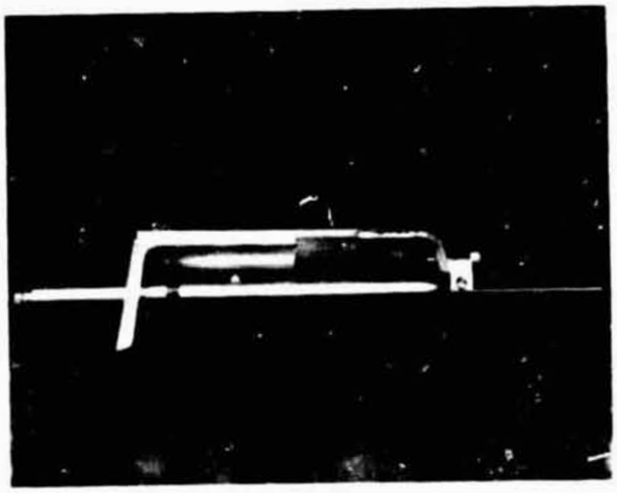

Figure 4. The stepped-horn acoustic atomizer for liquid sample deployment.

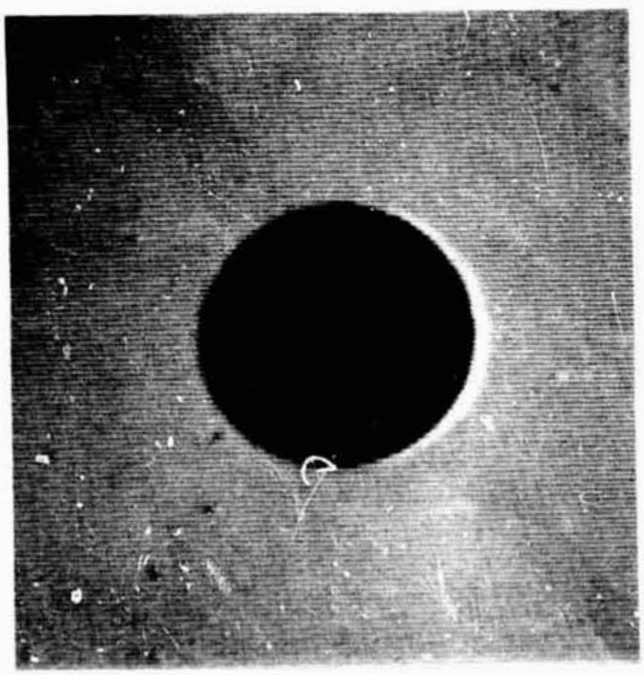

Figure 5. A glass microballoon immersed in water. The buoyancy force pushes the glass microballoon upward.

Figure 6. A water-coated glass microballoon with a strong core-centering force on.

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