8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

LEVITATED DROPLET OSCILLATIONS AND RAYLEIGH FREQUENCY CORRECTIONS: EFFECT OF INTERNAL FLOW

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Key Words: *Magnetic levitation, droplet oscillation, free surface flow, material properties.*

ABSTRACT

Droplets of electrically conducting materials are levitated in an AC field for the purpose of measurement of thermo-physical properties of metals in the liquid state [1,2]. Levitation is achieved through the induced current in the levitated volume that results in a lifting and confining Lorentz force. This force needs to balance the weight of the liquid, so it is quite large under full gravity, generally leading to a rigorous turbulent stirring of the melt and to a non-spherical equilibrium shape. The authors have modelled this situation in both terrestrial and microgravity conditions [3] and have previously shown that both factors affect the accuracy of material property value measurements, especially for the viscosity [4]. Microgravity experiments are thought to be more successful, since a much smaller magnitude force is necessary to position and confine the droplet. The shape then deviates only slightly from the spherical and Rayleigh's linear theory for the oscillatory response, following a small perturbation, remains valid. However, even in microgravity, Lorentz force induced stirring plus the effects of thermo-capillary convection, have a dissipating rotational component likely to affect the shape and damping. The numerical model permits to analyze in detail different scenarios of the droplet levitation techniques and the importance of the internal rotational flow effects. Figure 1 demonsrates the flow and the temperature distribution at the quasi-steady oscilatory state of small amplitude in the idealized conditions of zero gravity. The magnetic field is uniform at a sufficient distance from the droplet, which in practice is created by the Helmholtz coil of two turns, giving about 30 mT field on the surface of the droplet. The internal flow in the 10 mm diameter droplet is so intense, that turbulence is generated (Re = 10^4). The surface oscillation in this case is remarkeably similar to the case predicted by the classical Rayleigh theory and the damping rate gives a predictable correlation to the viscosity level, corresponding to the effective viscosity, as enhanced by turbulence. In a sharp contrast to the previous case with the intense internal flow and the turbulence, the case presented on the right of figure 1 accounts only for the electromagnetic pressure effect on the surface of the liquid droplet. This, in principle, should correspond to the linear zero skin-depth theory used for the magnetic levitation experiments [1,2]. In this case the turbulence is not generated (even if the numerical code has it activated) because (i) the velocity magnitudes are very low, (ii) the flow is nearly potential with the strain rate equal to zero. The resulting surface oscillation frequency corresponds to a 3 digit accuracy to the

Rayleigh frequency, 18.90 Hz in this case. However, if the fluid is assumed to be laminar and the turbulence model is not invoked, then in the case of the full electromagnetic force, the internal flow grows and affects the surface shape and oscillation pattern, which finally looses stability as demonstrated in the Figure 2. The observed oscillation spectra are shifted from the Rayleigh's value, and two additional peaks appear.

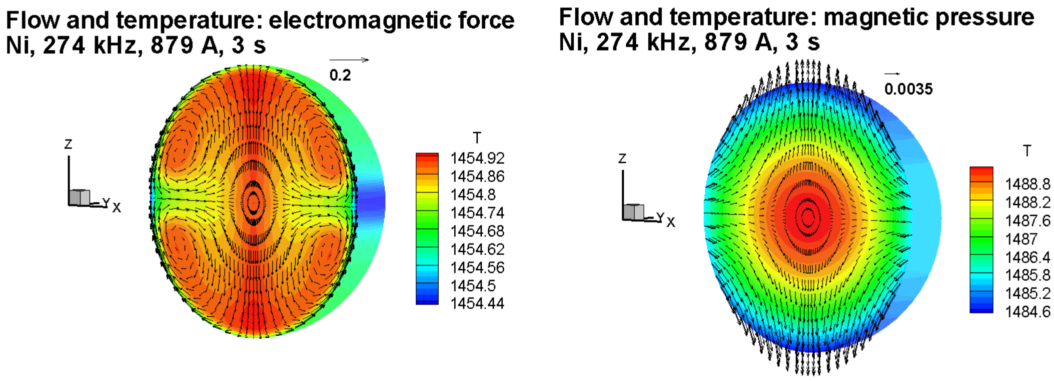

Figure 1. Internal flow and temperature: (left) when the full electromagnetic force is included; (right) when the electromagnetic pressure only is implemented.

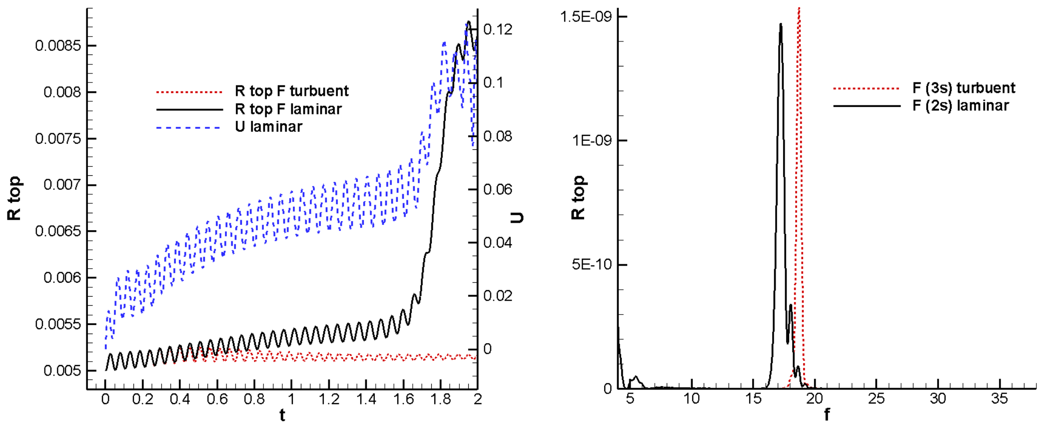

Figure 2. Effect of the turbulence generated by the internal flow: (left) oscillation patterns; (right) frequency spectra.

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