A Comparative Modeling Study of Magnetic and Electrostatic Levitation in Microgravity

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Magnetic and electrostatic levitation processes are two systems that will be used for thermophysical property measurements and fundamental study of solidification phenomena in microgravity environment. The objective of this newly-funded research is to develop comprehensive numerical models for electrostatic and magnetic levitation processes for microgravity applications and to apply these models to address the following four key issues concerning the use of magnetic or electrostatic levitation in space: (1) viscous surface oscillation and heat transfer of droplets levitated magnetically or electrostatically; (2) turbulent flow behavior in magnetically-levitated droplets; (3) internal fluid flows and heat transfer in electrostatically levitated droplets; and, (4) stability of droplets levitated magnetically or electrostatically.

Numerical models will be developed to represent the electromagnetic, transport and free surface phenomena associated with levitated drops in magnetic and/or electrostatic levitation systems. The model development will be based on our existing finite element and boundary element computational methodologies that have been developed by our research group in the recent years. Both 2-D and 3-D models will be developed. The models will be used for study of electromagnetic and transport phenomena associated with magnetically and/or electrostatically positioned melt droplets in space vehicles. These models will be checked against available analytical solutions and will be tested and refined against available ground-based and/or space flight experimental measurements. With these models, information on the viscous surface oscillation, internal recirculating flows driven by electromagnetic forces (in the case of magnetic levitation) or surface tension (in the case of electrostatic levitation) and temperature decaying and sample stability will be obtained as a function of magnetic and electrostatic levitation operating conditions such as applied voltage, electrode arrangement, electric charge conditions, applied current conditions and coil configurations, drop size, and types of materials to be used. The information will be used to understand the behavior of magnetically or electrostatically levitated droplets in microgravity and to make a comparative assessment of capabilities and flexibilities of magnetic and electrostatic levitation for microgravity research.

Direct numerical simulations (DNS) will be carried out and information on turbulent intensities, Reynolds stresses, instantaneous flow structures, and turbulent transport will be obtained to elucidate the fundamentals governing the turbulent magnetically-driven flow in magnetically levitated drops. The DNS results will also be used to calibrate the existing high and low Reynolds number turbulence models so that they be incorporated into the numerical models described above, thereby providing more accurate predictions for the magnetically levitated droplets. This information will be of critical and yet immediate value in helping the current endeavor on conducting experiments for viscosity measurements with the TEMPUS device in microgravity and interpreting the measurements taken in space flights.

This research project focuses on the study of electromagnetic and transport phenomena associated with magnetic and electrostatic levitation processes for microgravity applications. The research

work will result in documented information and useful numerical tools crucial for an in-depth understanding of the fundamentals governing the behavior of magnetically or electrostatically levitated drops. The information and tools will also be of critical value for design and development of magnetic or electrostatic levitation facilities in space vehicles and the international Space Station, for rational planning of microgravity experiments with magnetic or electrostatic levitation and interpreting the measured results in levitated drops, and for selecting either magnetic or electrostatic levitation whichever best suited for appropriate applications.