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NON-CONTACT TEMPERATURE REQUIREMENTS (NCTM) FOR DROP AND BUBBLE PHYSICS

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Many of the materials research experiments to be conducted in the Space Processing program require a non-contaminating method of manipulating and controlling weightless molten materials. In these experiments, the melt is positioned and formed within a container without physically contacting the container's wall. An acoustic method, which was developed by Professor Taylor G. Wang before coming to Vanderbilt University from the Jet Propulsion Laboratory, has demonstrated the capability of positioning and manipulating room temperature samples. This was accomplished in an earth-based laboratory with a zero-gravity environment of short duration. However, many important facets of high temperature containerless processing technology have not been established yet, nor can they be established from the room temperature studies, because the details of the interaction between an acoustic field and a molten sample are largely unknown.

Vanderbilt University's Center for Microgravity Research and Applications (MRA) was founded in 1988 to investigate the basic physics of drops and bubbles, and the influence of gravity on their properties. Containerless science experiments are conducted to study:

- drop dynamics;
- bubble dynamics;
- collision and coalescence;
- containerless science and technology;
- applications research.

The observation of these phenomena will lead to a better understanding of the contributions of fluid dynamics in the formation of raindrops, dispersal of aerosols in the atmosphere, manipulation of molten materials in a microgravity environment, etc.[1]

Drop dynamics involve the observation of acoustically levitated silicone oil drops at temperatures near room temperature. We are interested in:

- the resonant frequencies of free and statically formed drops;
- non-linear large amplitude oscillations;
- oscillation-induced rotation and fission;
- ratio of decay of oscillating drops.

In bubble dynamics[2], we are interested in the centering characteristics of the internal void, in addition to:

- rotational and vibrational behavior of free liquid shells;
- mode splitting and coupling;
- core centering mechanisms.

Concerning the collision and coalescence behavior of drops and bubbles, we consider:

- drop deformation upon collision;
- energy dissipation upon coalescence;
- drop separation and rupture.

In these experiments, we seek to set up stable low temperature environments, where the drop or bubble is in thermal equilibrium with its surroundings. Temperature measurement requirements under these circumstances are relatively straightforward and non-demanding, as shown in the Table.

At MRA, we are also interested in Containerless Science and Technology, which mandates a different set of NCTM requirements. These experiments study the properties of levitated molten metals. Of interest are:

- the stability of the containerless system;
- the shaping of liquid drops in an acoustic field;
- thermal acoustic intereactions (thermal streaming phenomena);
- effects of acoustics on nucleation and undercooling.

We are applying both electromagnetic levitation and acoustic levitation methods to the processing of molten metals. These require NCTM in a higher temperature range, as indicated in the Table.

In the case of thermal streaming phenomena, we are interested in making a set of closely spaced temperature measurements across a two-dimensional pattern of several centimeters. We want to distinguish the temperature of the suspended sample from the temperature distribution in the field surrounding the sample. Studies of this kind help to distinguish the regimes of gravity-dominated and acoustically-dominated fluid flow interactions with the specimen. We feel that a thermal imaging system with a spatial resolution quoted in the Table may be most appropriate.

At MRA, we are employing novel material characterization technologies, which may also be utilized as NCTM techniques.

Synchrotron x-ray microtomography has been developed since its suggestion in 1983 for the nondestructive evaluation of small samples.[3] X-ray tomography is a method of reconstructing the three-dimensional distribution of x-ray attenuating material within a volume. The technique is described elsewhere.[4]

Essentially, the technique utilizes a monochromatic x-ray beam from an electron storage ring to electronically collect a set of x-ray radiographs on a high resolution solid state television system. The radiographs are collected at a number of discrete rotational displacements of the specimen in the x-ray beam, and reconstructed with the aid of a computer to form a 3-D representation of attenuating material within the specimen. X-ray mictrotomography has been successfully demonstrated on both solid and liquid media. The state of the art is able to achieve a 1μm spatial resolution for a 1% variation in the local x-ray attenuation coefficient, under the best experimental conditions.[5]

For an x-ray beam of intensity I_0, the intensity transmitted through a slab of material of thickness L is given by

$$I=I_0e^{-\mu L}$$

where μ is the linear absorption coefficient. It is a function of the atomic number of the attenuating material and the x-ray photon energy. For the 25 KeV photons employed at storage rings for microtomography, the dominant attenuation process is the photoelectric effect.

In general, in a specimen which is a mixture of materials of varying atomic number, the total linear absorption coefficient is given by a mixture rule

$$\mu_{mix}= [\ \Sigma_i\ W_i\ (\mu/\rho)_i]\ \rho_{mix}$$

where W_i = weight fraction of the ith component and (μ / ρ) = the mass absorption coefficient for the ith element.

Here we see that a measurement of attenuation coefficient is sensitive to the atomic composition, and also to the density (ρ). Thus, in chemically homogeneous material, measurement of μ can yield information on ρ.

Such a situation can be envisioned at the solid/liquid interface. Often, in metal systems, the difference in density between solid and liquid phases can be a few percent, well within the detectability of x-ray microtomography. By assuming equilibrium conditions, the melting temperature at the solid/liquid phase boundary can be sensed in such a two-phase system.

In addition, in material systems such as Pb-Sn[6], which have well-defined density versus temperature relationships, the measurement of density variation with position within a sample can be equated with temperature measurement.

At MRA, we are currently applying this technique to the characterization of metal shells, and also solid/liquid phase boundaries in low-melting temperature metals.

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REQUIREMENTS FOR NON-CONTACT TEMPERATURE MEASUREMENT

	Temperature Range	Spatial Resolution	Temporal Resolution	Temperature Gradient
Drops, Bubbles Collision and Coalescence	10°<T< 40°C ±1%	1 measurement/cm	1 measurement/min	1° C/cm
Containerless Science and Technology	20°<T< 2000° C ±1%	50 measurement/cm	60 measurement/min	10^{-4} ° C/cm