HEAT AND MOMENTUM TRANSFER TO PARTICLES IN THERMAL PLASMA FLOWS

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ABSTRACT
Injection and processing of particulate matter in thermal plasma flows offer interesting possibilities for the improvement of existing and the development of new technologies and new processing routes. Plasma spraying, spheroidization and densification, plasma processing of fine powders including plasma synthesis are typical examples. Thermal plasmas with temperatures typically in the order of 10 K provide extremely high heating rates for injected materials and also high quench rates for the products. The latter aspect is of particular importance for plasma synthesis and for taking advantage of rapid solidification processes.

Over the past years thermal plasma processing attracted increasing attention. Progress in terms of industrial developments, however, is still hampered by serious gaps in our understanding and control of the interaction of particulate matter with thermal plasmas.

A thermal plasma reactor is a highly heterogeneous system with large temperature and velocity gradients. Over a distance of 10 μm, the temperature may drop from 15,000 K to almost room temperature, or the velocity may drop from 500 m/s to almost zero. In such a system, the particles must pass through the hottest region in the plasma with maximum possible exposure time. For some applications, it is desirable to transfer the proper amount of momentum from the plasma to the particles before impingement on a target. One of the key factors for satisfying these requirements is the control of the trajectories and the heat and mass transfer between the particles and the plasma.

In the first part of this paper, a brief review will be presented combined with a detailed analysis of the terms which enter the equation of motion. Heat and mass transfer between plasmas and particles, including the effects of injection parameters and coupling between particles and plasmas, will be discussed in the second part.

The results related to momentum transfer indicate that (i) the correction term required for the viscous drag coefficient due to strongly varying properties is the most important factor; (ii) non-continuum effects are important for particle sizes < 10 μm at atmospheric pressure and these effects will be enhanced for smaller particles and/or reduced pressures; (iii) the Basset history term is negligible, unless relatively large and light particles are considered over long processing distances; (iv) thermophoresis is not crucial for the injection of particles into thermal plasmas; (v) turbulent dispersion becomes important for particles < 10 μm in diameter.

Results associated with heat and mass transfer show that (i) convection heat transfer coefficients require extensive
modification due to strongly varying plasma properties; (ii) vaporization defined as a mass transfer process corresponding to particle surface temperatures below the boiling point, describes a different particle heating history than that of the evaporation process which, however, is not a critical control mechanism for interphase mass transfer of particles in thermal plasmas; (iii) particle heat transfer under non-continuum conditions is governed by individual contributions from the species in the plasma (electron, ions, neutrals) and by particle charging effects.