# Effect of Liquid Precursors on Powder Vaporization in an RF Plasma Spray

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*Summary:* Plasma spray with liquid precursors attracted increasing attentions over recently one decades, since it resolves the feeding problems common in direct injection of solid powders and it allows having a controlled injection of much finer particles than in conventional thermal spraying. In present paper, numerical analysis is conducted for the evolution of suspension particles in an inductively coupled plasma (ICP) in order to investigate the effects of liquid precursors on the evolutions of particle size, temperature and velocity. Results show large suspension droplets not always leads to the delay of powder vaporization. It is interesting to find that with an injection angle, the powders suspended in large drop evaporate more quickly.

## INTRODUCTION

Suspension plasma spray, introducing the material to be sprayed as a suspension of micro- or nano-sized powders dispersed in a liquid carrier, allows the controlled injection of much finer particles than in conventional thermal spraying.The suspension feeding is prepared by the coating material (metal, ceramic, biomaterial), in the form of powder with sizes ranging from 30 to 200 nm [1], dispersing in a liquid carrier (ethanol or water or a mixture of both). As shown in Fig.1, suspension will experience three stages after injecting into the plasma field. Firstly, the suspension is introduced into the plasma jet through an injection nozzle using a pressurized gas to shear the suspension and thus atomize it into a stream of fine droplets. Secondary, upon injection to the plasma field, with temperatures in the order of 10,000 K, the solvent is vaporized and some nanoparticles are flash agglomerated/sintered in the plasma jet. Finally, the nano or agglomerate particles undertake heating, melting or even evaporation before impinging onto the substrates.

The introducing of liquid precursors will influence the particles size and their trajectories, which further have profound influences for the particle heat treatment and final status. Understanding the effect of liquid precursors on powder vaporization is of importance for the successive coating or synthesis [2]. In present paper, a comprehensive two-dimensional numerical model is used to investigate the evolution of particle size, temperature, velocity and trajectory both for the suspension plasma spray and conventional thermal spraying in an ICP torch. Results shows for the effects of liquid precursors on powder vaporization are obviously influenced by the injection angle and droplet size.

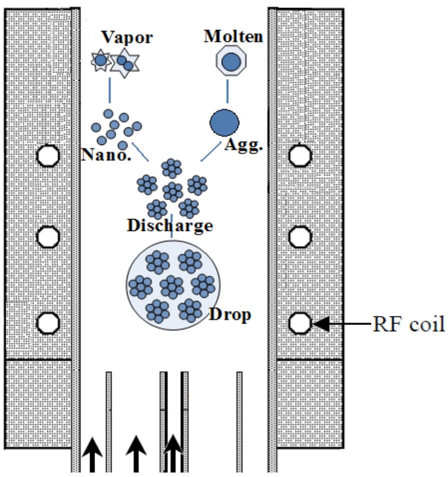


Fig.1 Schematic of RF plasma spray

## MATHEMATICAL MODEL

The mathematical models for RF suspension plasma spray system include plasma model and particle model. The RF plasma is sustained by receiving the electromagnetic energy from the induction heating system. By solving the plasma gas equation, the information on conditions external to the particles can be derived. The effects of in-flight particles on the plasma are neglected in present study for the dilute spray system. For the plasma filed, the governing equations of the velocity, temperature and species concentration are solved using the SIMPLE algorithm. The computational simulations are performed on a two-dimensional cylindrical domain with the uniform staggered 160 × 120 grids in axial and radial directions respectively. The computational domain for the electromagnetic field is extended to the outside of plasma region, using the non-uniform 282 × 175 grids in axial and radial directions respectively. The boundary condition of the electromagnetic field and the flow field are similar to [3].

Particles (including droplet particles and solid particles) are treated as a discrete Lagrangian entity that exchanges mass, momentum, and energy with the plasma gas. The particles' acceleration and heating are tracked through out their flight. The comprehensive partical model considers in-flight particle physical phenomena such as accelerating, solvent evaporation, solid particles discharge, heating, melting and evaporation. Particle heat transfer is described by the lumped heat capacity model and the non-continuum effects and the influence of the evaporation on the heat transfer are considered. Details description of the particle model and particle properties can be seen in Ref. [3~ 4].

## RESULTS AND DISCUSSION

Figure 3 and 4 show particle radius, temperature, velocity for case of particle injection angle $\theta = 0^{\circ}$ and $\theta = 3^{\circ}$, respectively. The suspension feeding method, which is injection of zirconia particles with the help of ethanol suspensions, are compared with the conventional feeding methods—the solid particle injection. The suspension drop radius for the case of Fig.3 is 2.5 $\mu$m, for Fig.4 is 3 $\mu$m, and the solid particle size is 2500nm in both. In Fig.3, it can be seen that the particle

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suspended in droplet is heated up slower than without the suspension. This is because the cases with suspension firstly undergo the solvent heating and evaporation process in which the absorbed heating are used to compensate the vaporization latent heat of alcohol and the temperature of the suspension will keep at the boiling point of 351 k for a while. Then after the solvent is totally vaporized, the temperature steeply increases for solid particles due to its small size. If the heating temperature and time is enough, the final status of the solid particle with and without the suspension is similar. While in Fig.4, the result is different, although the droplet size of Fig.4 is much larger than that in Fig.3, the case with suspension is heated faster than that of without liquid precursor. It is reasonable that larger suspension droplet needs more energy to compensate the latent heat of evaporation, hence prolong the suspensions flight distance and shorten the solid particle heating time. Why the final size of the solid particle suspended in droplet is smaller than that without suspension?

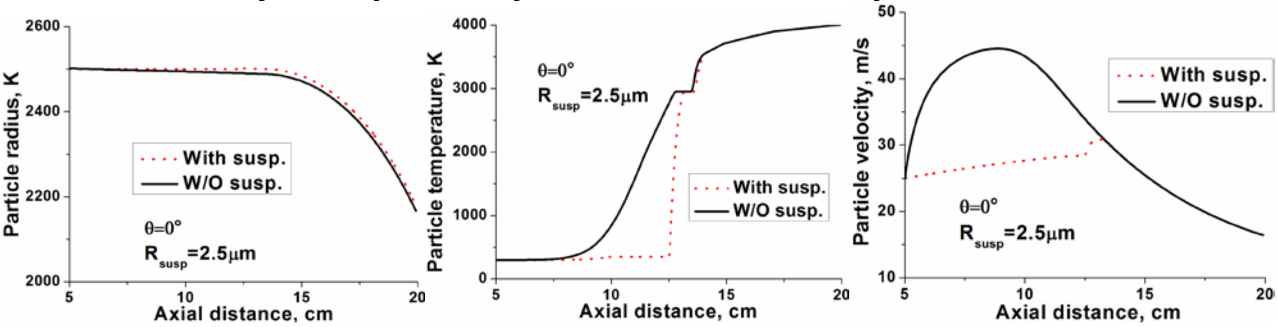



Fig.3 Particle radius, temperature, velocity with and without suspension for $\theta = 0^{\circ}$, $R_{susp} = 2.5\mu m$

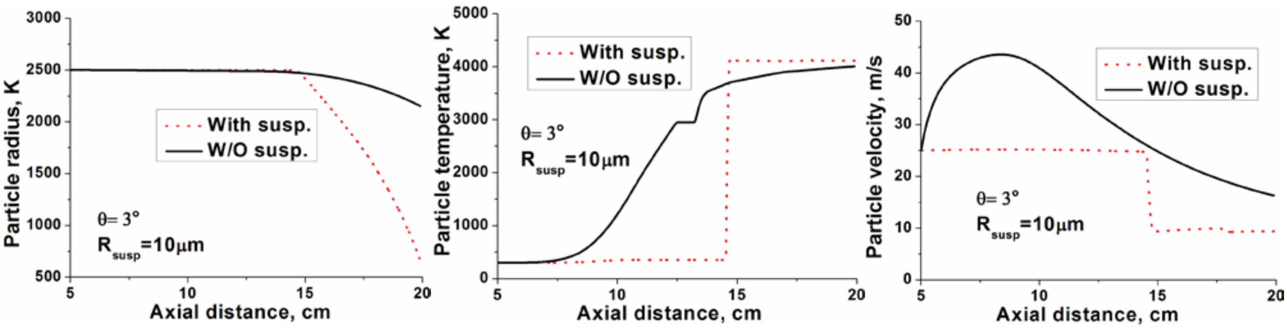
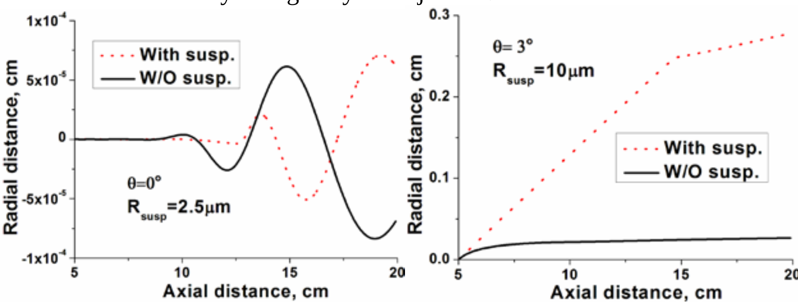



Fig.4 Particle radius, temperature, velocity with and without suspension for $\theta = 3^{\circ}$, $R_{susp} = 10\mu m$

The reason of this phenomena lies in that the micro-size suspension droplet with large inertia is accelerated steadily by the gas stream and its trajectory goes straight. With an injection angle (unequal to zero), the straight flight trajectory will take the particle closing to the plasma core which is the highest temperature of plasma filed located. As Fig.5 shows that in the case of injection without suspension, the particle fluctuates earlier than that without the protection of the solvent. Fig.6 indicates the plasma core resides at the sides of the axis. The temperature of the region near the axis is relatively low, due to the cooling effect of the carrier gas with low temperature and large flow rate. Therefore, on one hand when the injection angle is zero, the particle trajectory fluctuated around the axis. Larger droplet leads to the delay of particle vaporization. On the other hand when the injection angle unequal to zero, droplet with large inertia is inclined to flight closed to the plasma core and get much more heating energy. The effects of liquid precursors on powder vaporization are not only influenced by droplet size but also obviously changed by the injection.



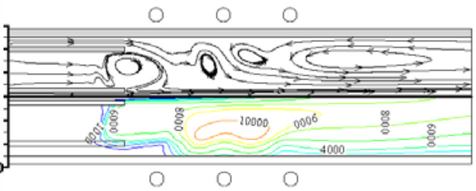




Fig.5 Particle trajectories of different injection angle

Fig.6 streamline and temperature contour in RF torch

## References

[1] Fauchais P., Etchart-Salas R., Rat V., Coudert J.F., Caron N., Wittmann-Teneze K.:Parameters controlling liquid plasma spraying: solutions, sols, or suspensions. *J. Therm. Spray Technol.* 17: 31-59, 2008.

**[2]** Buchner P., Schubert H., Uhlenbusch J., Weiss M.: Evaporation of zirconia powders in a thermal radio-frequency plasma. *J. of Thermal Spray Technology*, 10(4):666-672,2001

**[3]** Qian L. J., Lin J.Z., Xiong H.B.: Numerical Modeling in Radio Frequency Suspension Plasma Spray of Zirconia Powders. *Plasma Chem. Plasma Process.*30: 733-760, 2010.

**[4]** Qian L. J., Lin J.Z., Xiong H.B.: Modeling of non-Newtonian suspension plasma spraying in an inductively coupled plasma torch. *International Journal of Thermal Sciences* 50:1417-1427, 2011.