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Materials Handling for Electrical Modification of a Complex Target Surface: Analysis and Feasibility

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Phase I Report

Materials Handling for Electrical Modification of a Complex Target Surface: Analysis and Feasibility

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Summary:

This project effort, conducted as feasibility investigations addresses the transport and deposition of particulates using traveling field, electrohydrodynamic atomization and gas carrier methods. The method of investigation was experimental, using existing experimental and pre-commercial apparatus. All methods were found to be successful to varying degrees. Preliminary results were presented at LLNL in a project review meeting. The most promising methods for particle delivery were electrodynamic atomization/spraying and gas-carrier propulsion. Traveling field delivery is limited by scale up considerations and the requirement for transport through close tolerances. Electrodynamic atomization requires use of low electrical conductivity liquid carrier phases but is scalable by ganging multiple orifices and atomizing tips. Gas carrier delivery is attractive because no liquid carrier is needed and momentum can higher than the other traveling field or electrodynamic processes. Subsequent phases of the project will address electrodynamic and gas-carrier delivery.

Background:

The task addressed in this project was to develop a method to meter, transport and deposit a spray or powder into an enclosed volume containing a complex target with multiple deposition sites.

Additional project criteria were provided by Dr. Joe Tringe of LLNL as follows:

Assumptions

- The target structures are metal electrodes on an insulating substrate, with component spacings appropriate to the voltages involved;
- Insulating components have solder joints where they attach to the substrate or each other;
- Electrical connections may be either bare or covered with a conformal coating, except for the points where solder joints are located.

Additional challenges

- The target region, approximately ~1 cm^2, may be embedded in a complex geometry of interfering objects, far from the delivery location of the particles/droplets;
- The resultant controlled discharge must be maintained in a discharged state for extended periods (many hours).

Technologies of possible interest

- Electrodynamic atomization of carrier liquids;
- Multilayer particles, such as Zn/ZnO or InGa/PVA
- Triboelectric charging of dry particles
- Evaporation of a liquid carrier after dispersion of suspended particles

Project activity:

Through collaborative discussions, the candidate approaches of three-phase traveling field transport, electrodynamic atomization and gas-carrier delivery were selected for experimental investigation. Each technology was determined *a priori* as being able to meet the project objectives.

Traveling field transport is a method for levitating and metering particulates along a linear array of high voltage electrodes (Figure 1). When actuated by a three-phase, phase-lagged excitation, the particles are charged and subsequently, levitated and propelled along the array of alternating legs of the three-phase alternating current field (e.g., Moesner and Higuchi, 1997; Gan-Mor and Law, 1992). The process has advantages of singulating individual particles from a bulk mass and requiring no carrier for the particles. The process has the disadvantages of limited mass transfer capacity and the creation of strong, transient electrical fields that could potentially affect sensitive electronic components in the proximity of the conveyor.

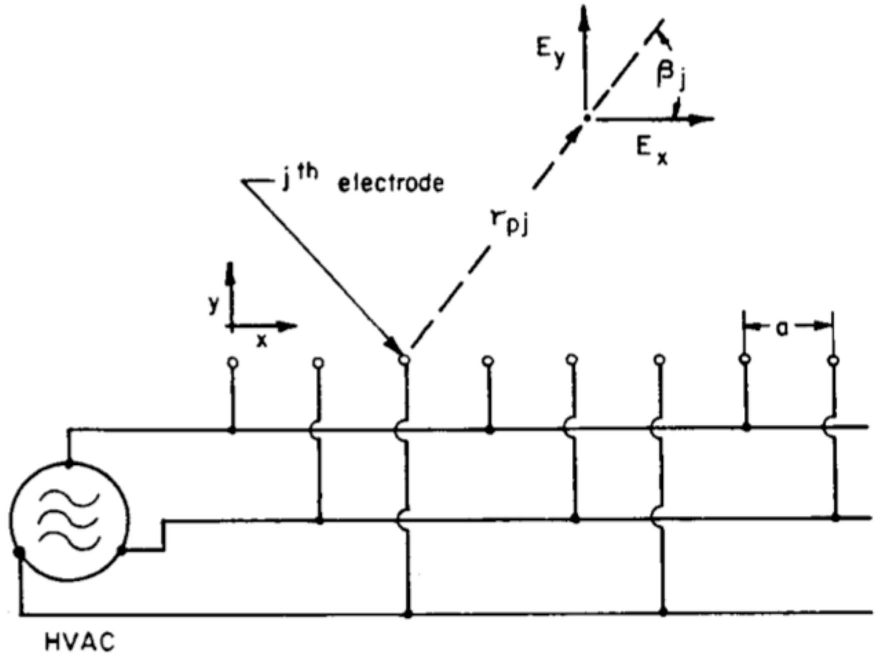

Fig. 1. Electric field component established at the particulate point by the *j*th cylindrical electrode of the three-phase ac panel.

Figure 1. Conceptual depiction of a three-phase traveling electrical field showing relationship between a particle location the resultant electric field (from Gan-Mor and Law, 1992).

The feasibility of traveling field delivery of LLNL-produced zinc oxide and copper-doped zinc oxide particles was determined by an empirical, experimental evaluation in the Applied Electrostatics Laboratory at the University of Georgia. The particles were successfully levitated and propelled along a 10 cm wide, 1 m long test conveyor. Excitation was from a 60 Hz, three-phase power supply with 120° phase separation. Peak voltages ranged from 1.5 to 4 kV. Mass flow rates were in the mg/s range. A series of video presentations, including a brief introductory lecture and demonstrations of standard test power (lycopodium spores) and LLNL particles were produced. The videos were supplied to Dr. Joe Tringe and used in project presentations. Figure 2 is a still photo from the zinc oxide transport video demonstration.

While traveling field singulation and metering of the particles is feasible, there may be additional operational considerations that preclude the further success of the method for delivering significant quantities of particulate into electrically shielded, complex targets. The particles do exit with grid with significant charge-to-mass ratios and can be electrically manipulated by supplemental electrical fields. However, they do not possess significant momentum for travel beyond grounded surfaces in close proximity. This may severely limit their utility in penetrating small openings. An additional attribute of the discharged particles is that they are all charged with the same polarity and therefore subject to dispersal due to the space charge associated with the cloud of particles. The cloud also creates its own electrical field and could potentially interfere with unshielded sensitive electronic components within close proximity.

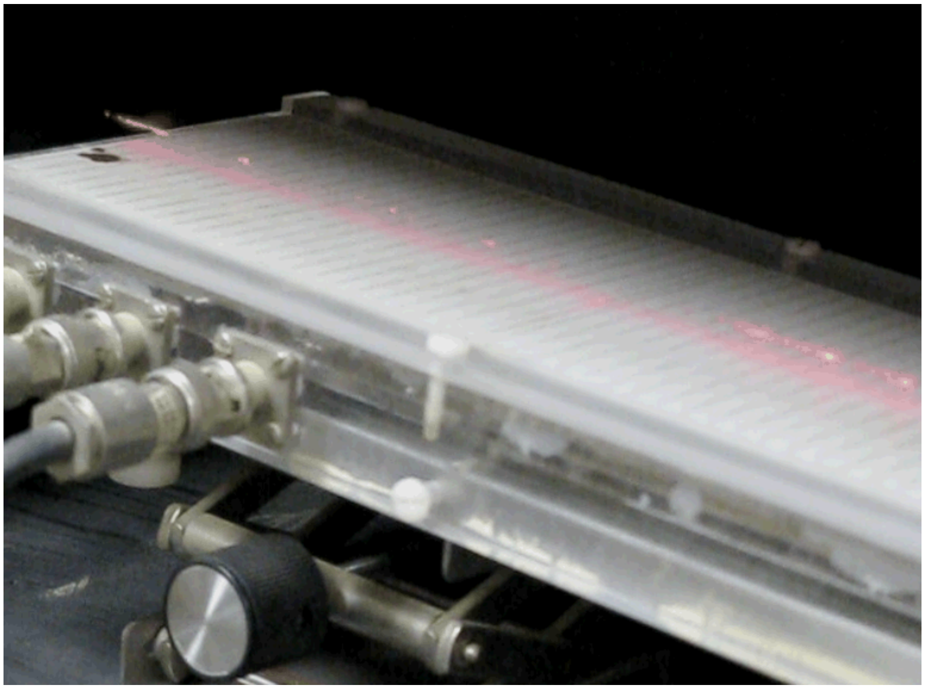

Figure 2. Traveling ac electric field transport of zinc oxide particles. Particles are moving right to left along the electrode grid and propelled off the trailing (left) edge of the grid. The red laser beam is used strictly as an aide to visualize the particle flow.

Electrodynamic (also called electrohydrodynamic) atomization is a spraying process in which an electrical gradient is used to overcome surface tension and produce a relatively monodisperse size distribution of droplets. Unlike induction and contact charging for electrostatic spraying where conductive liquids are used, electrodynamic spraying is suitable only for liquids having relatively high electrical resistivities in order to establish and sustain strong electrical gradients within the liquid stream.

The general principle of electrodynamic atomization is shown in Figure 3. Under low pressure and shear, a filament of liquid is expelled from an orifice structure maintained at a high electrical potential (>2 kV). Optionally, a guard structure, maintained at ground or the opposite polarity of the liquid filament, can be positioned downstream of the liquid exit and establish the electrical gradient necessary for atomization (Coffee, 1987). The droplet size of the resulting liquid atomization is controlled by the excitation voltage, the surface tension of liquid, the liquid flow rate and the liquid filament diameter, among other parameters. Alternatively, the spray target can be maintained at ground potential or the potential manipulated to achieve the desired electrical field gradient (e.g., Inculet, 1992) as shown in Figure 4.

Advantages of electrodynamic atomization are that relatively low electrical power is required for atomization and no mechanical power, other than low pressure liquid pumping, is required. The process is silent and when fluid properties are controlled within a narrow range, the process is robust and stable. Disadvantages include the limitation of using only electrically resistive liquids, relatively low flowrates (< ml/min range) per atomizer and the effects of grounded and other objects in the proximity of the atomizer.

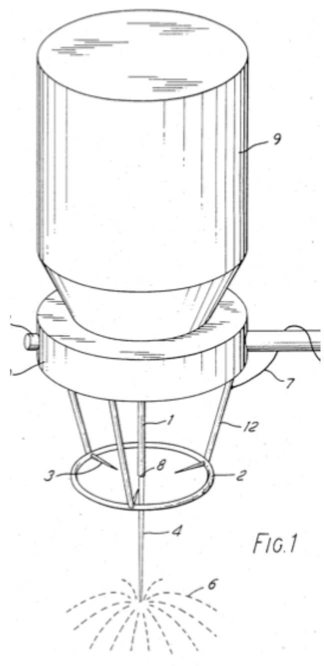

Figure 3. Principle of electrodynamic atomization in which a liquid filament is subjected to an electrical gradient to overcome surface tension and form charged spray droplets (from Coffee, 1987).

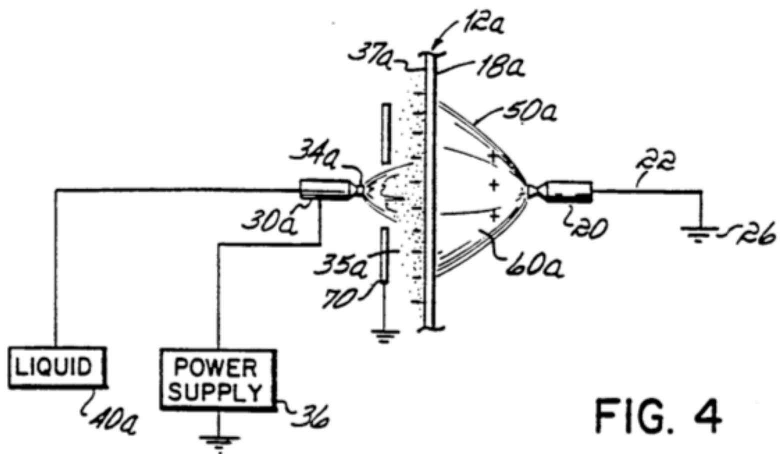

FIG. 4

Figure 4. Electrostatic atomization and coating process where the target electrical characteristics are manipulated in order to enhance coating deposition. Target plane is Item 12a in figure and coating side is 37a; charge 60a is used to increase field strength (from Inculet, 1992).

Electrodynamic atomization was investigated in this project through empirical experiments at UC Davis. Collaboration was established with Edward Escallon at Terronics Development, Inc., a commercial producer of custom electrodynamic atomizers and other electrostatic equipment for specialized industrial applications. Terronics supplied a prototype "dart' atomizer machined from Delrin® (Figure 5). The tip is supplied by a capillary flow (assisted by a syringe pump for supply) through a shimmed supply housing (Figure 6).

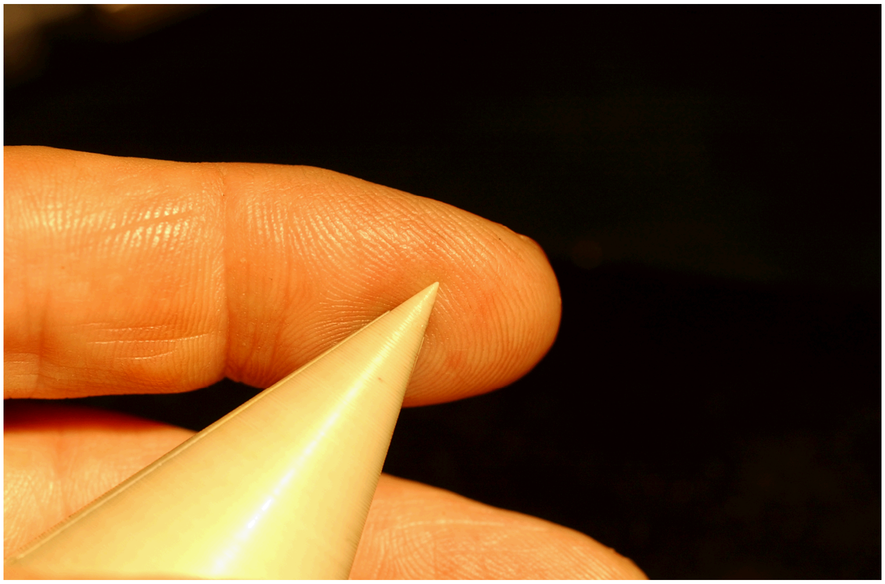

Figure 5. Electrodynamic atomizer tip used in UC Davis experiments as supplied by Terronics Development, Inc. Atomizer is a "dart" configuration machined from Delrin.

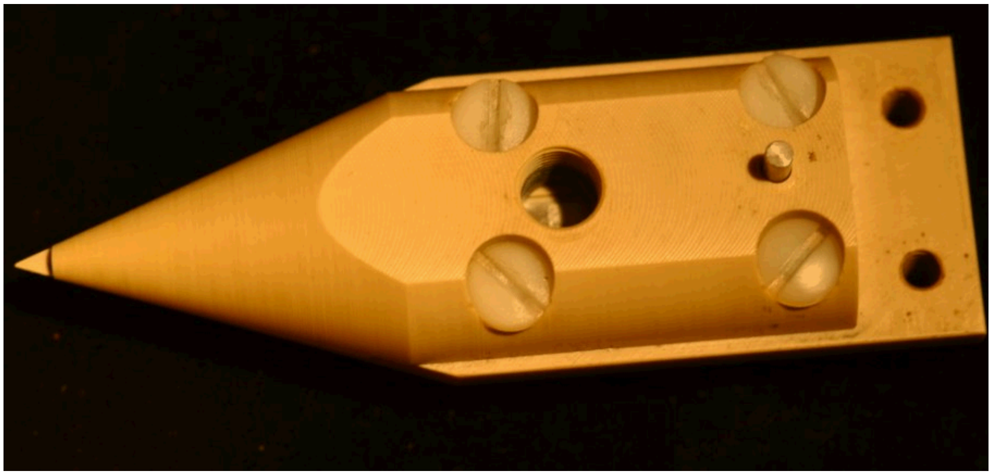

Figure 6. Electrodynamic atomizer used in UC Davis experiments as supplied by Terronics Development, Inc. Liquid flow into atomizer is through the 1/8"NPTF threaded port in the center and high voltage supply is through the stainless steel pin to right of liquid port.

Feasibility experiments were conducted at UC Davis using the particulates of coal powder (milled to 10 – 30 μm dia.) supplied by Terronics and zinc oxide supplied by LLNL. Ethanol was chosen as the liquid carrier due to high electrical resistivity, rapid evaporation rate and lack of residual material after evaporation. Experiments were also conducted with polyethylene glycol (PEG) and atomization was successful; however, PEG did leave the expected residue on target surfaces. Typical solid:liquid concentrations were in the 5% v/v range. Electrical excitation voltage was ~ 5 kV. Atomization and deposition of zinc oxide suspended in ethanol and PEG are shown in Figure 7 and 8, respectively. The effect of multiple targets in the spray field can be seen in Figure 9 where a grounded lab spatula can be seen deflecting the spray. The experiments established the feasibility of suspending, atomizing and depositing LLNL produced particles using electrodynamic atomization.

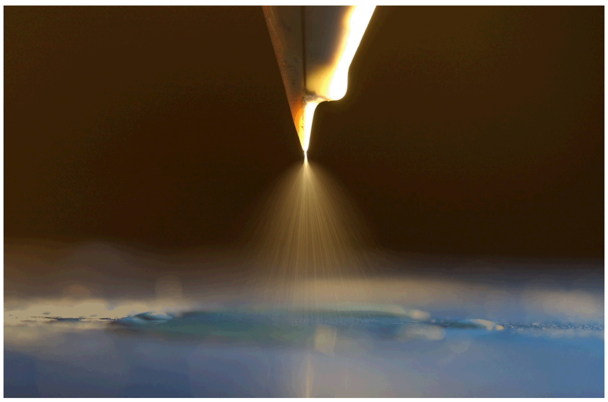

Figure 7. Zinc oxide in ethanol.

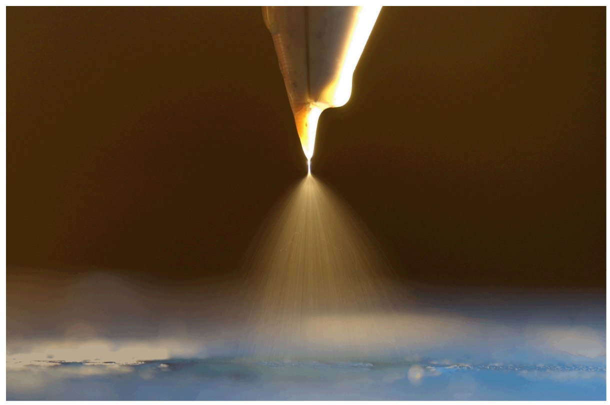

Figure 8. Zinc oxide in PEG.

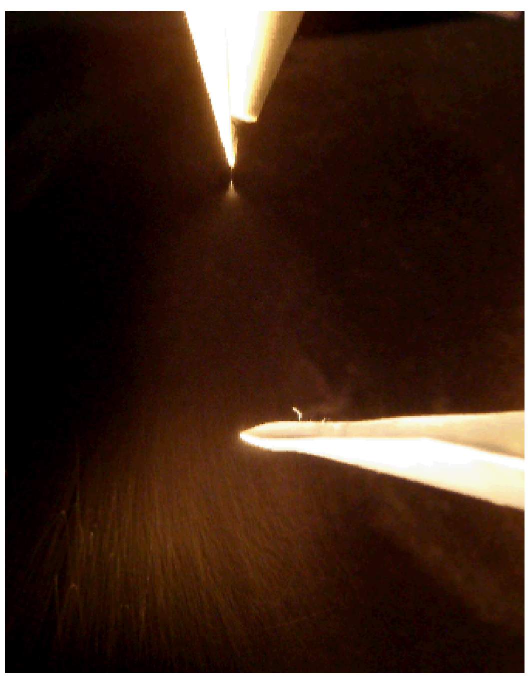

Figure 9. Deflection of spray path caused by grounded spatula placed in proximity of spray.

One additional approach to particulate delivery was investigated, viz., dry gas transport. In this design, a carrier gas was used in combination with a micro-Venturi to introduce and suspend the particles within the carrier. A prototype lab assembly was fabricated at UC Davis and tested by attempting to coat the interior of a laboratory flash with coal powder. The concept is based on a design where the micro-Venturi is embedded within a carrier flow nozzle (Figure 10) and the particulate supplied as a suspension within a volatile liquid, such as ethanol or possibly from a fluidized bed.

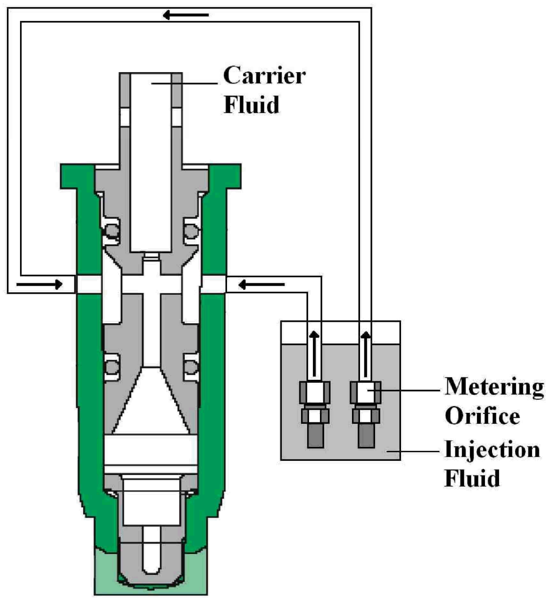

Figure 10. Dry carrier concept for entraining particulate powder into a carrier gas using a micro-Venturi design.

The simple prototype design is shown in Figure 11. When supplied with compressed air at apprx. 100 kPa, sufficient vacuum was generated by the micro-Venturi to entrain coal powder into the carrier gas and to propel the mixture into a test flask. While no attempt was made to optimize the design, the experiment revealed that significant mass of powder could be delivering into an enclosed volume very quickly and produce relatively thick deposition (Figure 12).

<u>Conclusions:</u>

Traveling field, electrodynamic atomization and dry carrier delivery are all feasible methods of delivering the desired particulates to target surfaces. However, the field deployment of electrodynamic atomization and dry carrier delivery is much more likely to be successful and will be further investigated. Subsequent phases of the project will involve more formal investigation and parametric studies and less empirical feasibility investigation.

Figure 11. Co-axial delivery of particulate into an enclosed volume (lab flask) using a micro-Venturi to entrain dry powder into the carrier gas (air) flow.

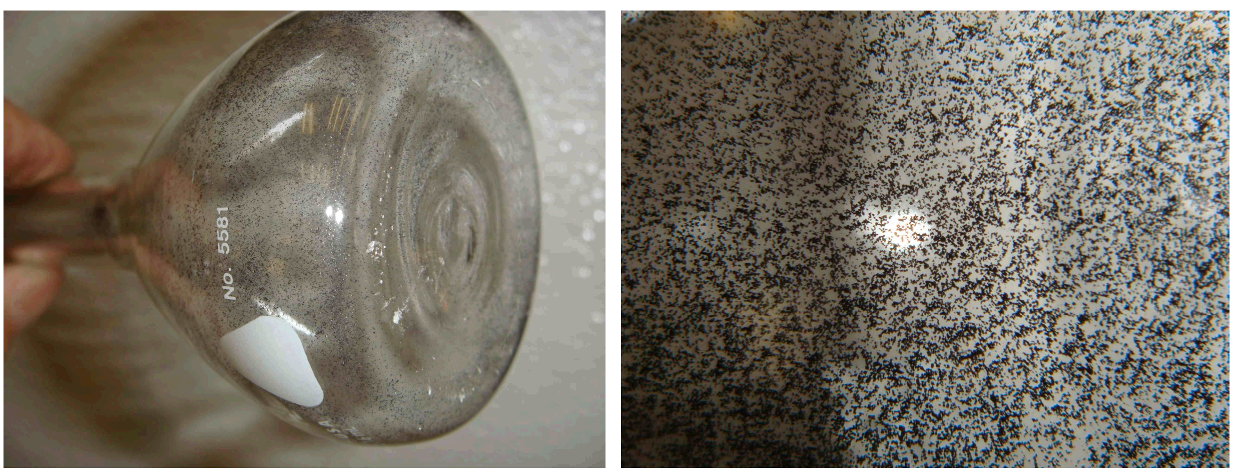

Figure 12. Deposition resulting from gas carrier delivery of particles into an enclosed, relatively difficult to coat surface.

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