Spray Characteristics of a Novel Multi Orifice Electrostatic Atomizer

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Abstract

A novel electrostatic atomizer has been developed using a planer faceted electrode as the emitter in place of the conventional single pointed electrode found in most other atomizers of this type. This novel design does not require precise alignment of the emitting electrode and allows an array of orifices to be used, instead of being restricted to the usual one, to atomize fluids. This allows for the first time an electrostatic atomizer to increase its flow rate whilst maintaining fine highly charged droplets.

Introduction

Conventional charge conduction atomizers working with non-conductive or semi-conductive fluids often use a single-point charging electrode in combination with a single discharge orifice, as discussed in [1&2]. In most cases the geometric alignment between the single point and orifice is extremely critical to the atomization performance of the unit. This traditionally leads to limitations in the minimum discharge orifice diameter and as the final droplet size is proportional to this orifice diameter, a limitation is imposed on the final atomization performance. Having a single discharge orifice also restricts the total fluid flow rate for a given pressure.

This paper presents experimental data from a novel electrostatic atomizer, as described in [3&4], which uses a Planer Faceted Emitting Electrode that does not need precise alignment of the emitting electrode over the extraction electrode. As the alignment requirements are significantly reduced, compared to a single point electrode, is it possible to operate this new atomizer with number of smaller diameter orifices from a single emitting electrode. This crucially permits high flow rates of fine highly charged droplets that has not been achieved with Electrostatic atomizers to date.

Planer Faceted Electrode Atomizer Construction

The emitting electrode of the atomizer is of planer design with a facetted micro structure as shown schematically in figure 1, and detailed in [3]. The use of a commercially available diamond burr is one of the most convenient methods of obtaining a surface structure suitable for this type of electrode, shown in figure 2.

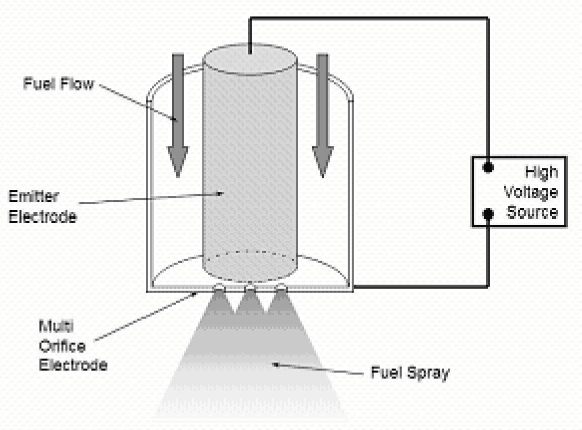

Figure 1. Schematic of planer faceted electrode.

Figure 2, Diamond Coated Faceted surface

The diamond coated emitting electrode is mounted in close proximity to an extraction electrode incorporating the fluid discharge orifices. An example of one of the test extraction electrodes can be seen in figure 3. In this example the working section is the central recessed area of 4mm diameter, with an array of 16 x 60µm fluid discharge orifices.

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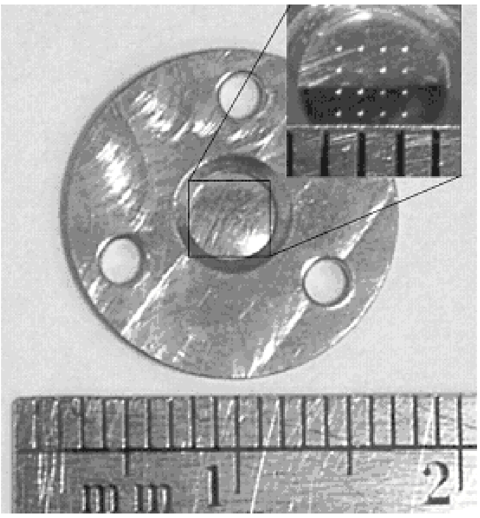


Figure 3. Extraction Electrode with Multiple discharge orifices.

For the experimental work discussed in this paper a pair of modular atomizer units, as shown in figure 4, were constructed with a vernier height control that allowed rapid and fine adjustment of the distance of the emitting electrode and the discharge orifice(s) in the extractor electrode. This distance is typically between 50µm and 200µm, with discharge orifices of 50µm to 150µm diameter. Single and multiple discharge orifices were used, but in all cases the orifices were associated with a single emitting electrode of 2mm diameter.

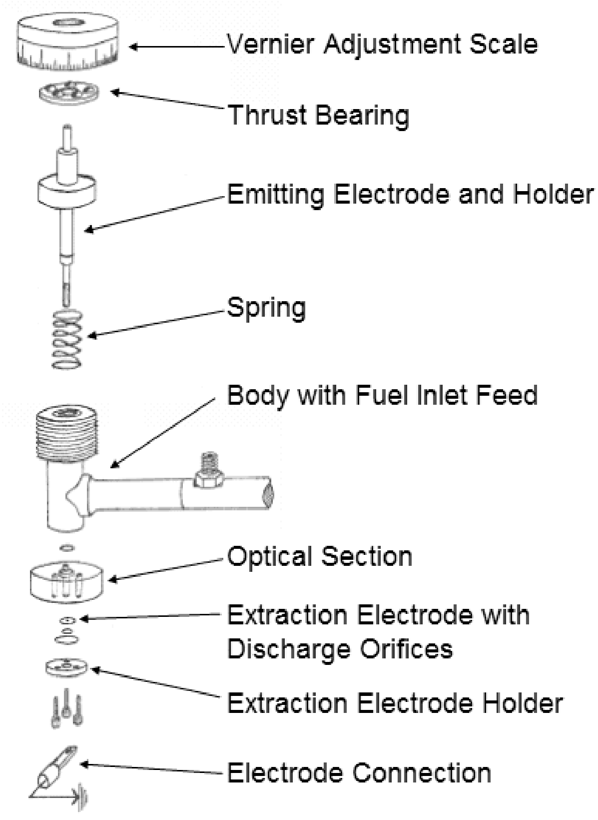


Figure 4 Modular Atomizer unit with vernier height adjustment for emitting electrode.

Results

Complimentary tests were carried out on two spray benches. One spray bench was at Scion-Sprays Ltd using a LaVision FlowMaster 3S CCD camera with an exposure time of down to 0.1µs with the resultant images being processed through Oxford Lasers VisiSolo software to determine droplet sizes (an example of this process is shown in figure 5 and 6). The other spray bench used was at the Mechanical Engineering Department of Imperial College London, using their own PDA system for droplet size analysis and a specially constructed charge collection unit and ammeter for spray charge measurements.

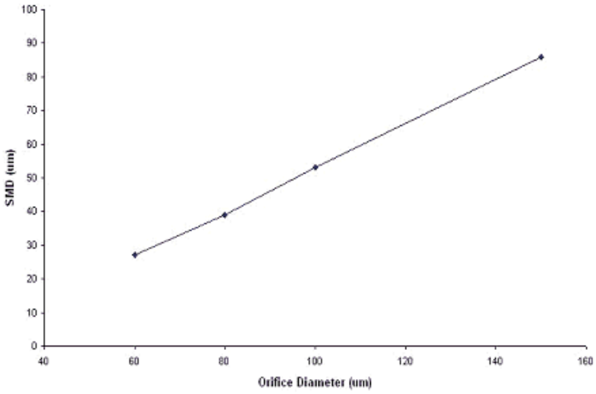


Figure 5, Relationship between discharge orifice size and droplet size.

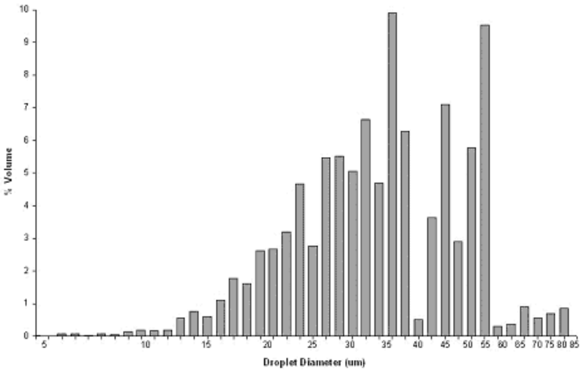


Figure 6 Droplet size distribution from a 60µm orifice, measured at 15mm downstream form the discharge nozzle exit.

Throughout these sets of experiments, the extraction electrode and discharge nozzles were all hand-made with discharge orifices being placed up to 0.8mm off centre from the nominal central axis of the 2mm diameter emitting electrode. All of these arrangements worked equally well so long as the orifice is located within the circumference of the emitting electrode. Therefore the axial alignment was found to be non-critical in the design of the atomizer. As a result the only limit to droplet size reduction is the manufacturing of the orifice itself.

These sets of experiments used drilled single orifices from 150µm to 60µm. Figure 5 shows the relationship between orifice size and final droplet size expressed as

Sauter Mean Diameter with gasoline as the working fluid at a supply pressure of 2bar. As can be seen from figure 5, an approximate linear relationship of

$$D_{SMD} = 0.5d$$

was found, where D_{SMD} is the Sauter Mean Diameter of the atomized spray measured at 15mm downstream of the atomizer discharge nozzle, and d is the discharge orifice diameter. Figure 6 shows the droplet size distribution form a 60μm orifice as collected using the LaVision CCD camera and VisiSolo sizing software, resulting in a 27μm SMD.

Throughout these sets of experiments no lower limit of the discharge orifice diameter was found with regard to the atomization characteristics, the present limitation on producing finer sprays was the simple orifice manufacturing process of drilling, limiting orifice sizes to 50μm or 60μm diameter.

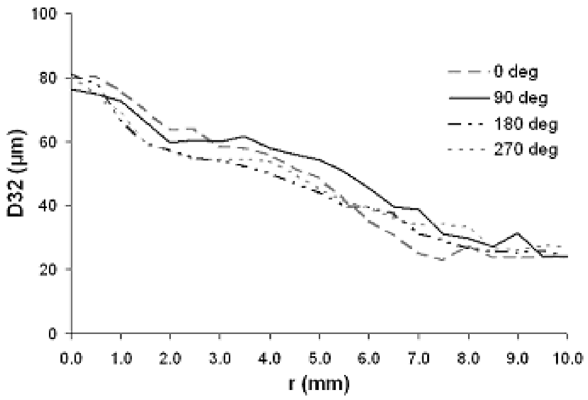


Figure 7 PDA results of SMD vs. radial position for a single 80μm orifice, with 30μm electrode gap 4.6kV applied voltage and 2bar gasoline supply.

The electrostatic spray structure generated by a single 80μm orifice was further examined using PDA equipment to analyse the droplet distribution in a horizontal plane across the spray cone at 15mm downstream from the discharge orifice. In figure 7 the SMD at each radial position in 0.5mm steps from r=0 to r=10mm is plotted for each of the 4 cardinal axis. The structure of the typical electrostatic spray can be seen in figure 7 as the smaller droplets are driven to the outside of the spray by the repulsive forces between the droplets while the heavier larger droplets remain on the spray axis. Figure 8 shows the accompanying axial velocity data for each of the measurement points, and it can be seen that the larger central droplets have maintained a higher velocity of almost 20ms^{-1} whilst the outer smaller droplets have slowed to virtually zero velocity due to aerodynamic drag, and actually show some slight signs of recirculation with a slight negative axial velocity.

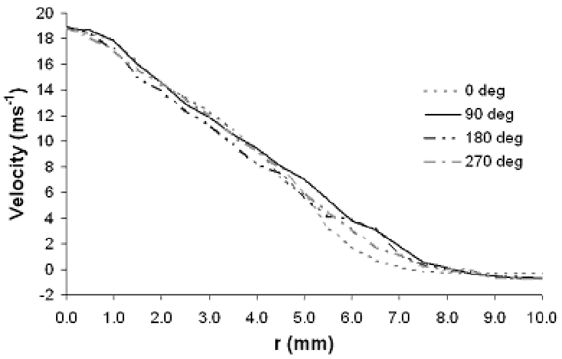


Figure 8. PDA results of Droplet Velocity vs. radial position for a single 80μm orifice, with 30μm electrode gap 4.6kV applied voltage and 2bar gasoline supply.

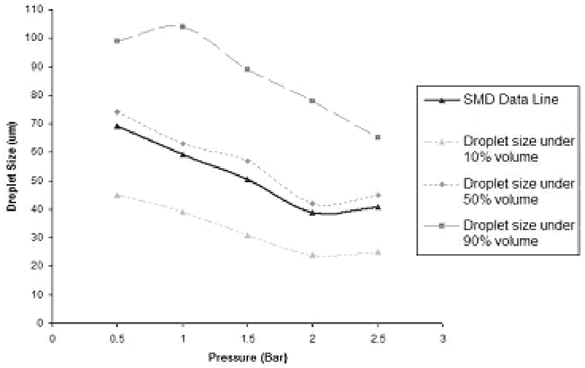


Figure 9, Relationship between droplet size and fluid supply pressure.

The effect of fluid pressure on atomization is shown in figure 9. This set of data was again collected at 15mm downstream from the 80μm discharge orifice using gasoline as the test fluid. It can be seen that the fluid pressure does have a significant effect on the final atomization, but it can also be seen that the electrostatic process is still very effective even at supply pressures as low as 0.5bar.

Figure 10 shows the effect on mean droplet diameter of varying the gap between the emitting electrode and the discharge orifice. The mean droplet diameter was measured with PDA equipment at 15mm downstream from the single 80μm orifice on the spray centreline. Gasoline was used as the working fluid. Here it can seen that the higher fuel pressure achieves the best atomization, but also that the electrostatic atomization process is remarkably tolerant of a range of electrode gaps and fluid pressures, indicating this design of atomizer is not overly sensitive to realistic manufacturing tolerances.

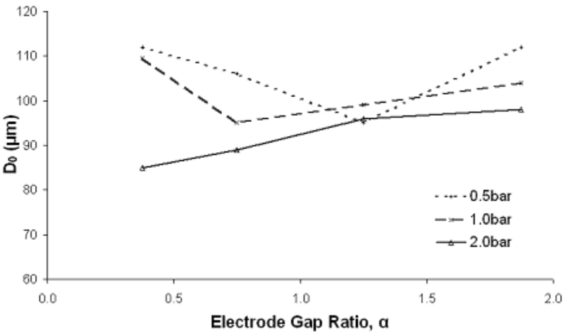


Figure 10. Mean Droplet Diameter vs. Electrode Gap Ratio for a single 80µm orifice, measured at r=0, z=15mm at 3 different fluid pressures.

Multi-Orifice Electrostatic Atomizer

The application of the planer faceted electrode with its insensitivity to discharge orifice location, allows the use of multiple discharge orifices, operating from the same single emitting electrode. This achieves a higher flow rate of finely atomized fluid than could be produced from a single orifice. The images in figure 11 show the fluid flow from 4 adjacent 80µm discharge orifices located under a single emitting electrode. In figure 11a the flow is shown with no applied voltage, resulting in no atomization, whilst the image in 11b shows the same jets with 6kV applied voltage, showing the initiation of fluid break-up of all 4 jets at the same time, and 11c shows the completed atomization at 15mm downstream.

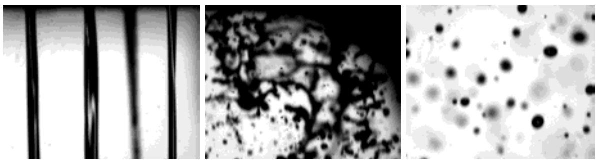


Figure 11. Multiple Orifice atomization, (a) 0kV, (b) 6kV applied voltage, (c) 6kV voltage at 15mm

Figure 12 is a schematic diagram of a 5 x 80µm orifice array operating from a single 2mm diameter emitting electrode that was used to generate the following set of results. The SMD results shown in figure 13 from this array were with gasoline at 2bar pressure, an electrode gap of 100µm and an applied voltage of 8kV. Figure 13 shows a good degree of symmetry across the whole spray indicating that all 5 of the orifices were atomizing to a similar degree. Figure 13, like figure 7, also shows that the smaller droplets have been pushed to the outside of the spray, though in this case with the multiple orifices there is a slightly larger radial spread of the larger droplets as well.

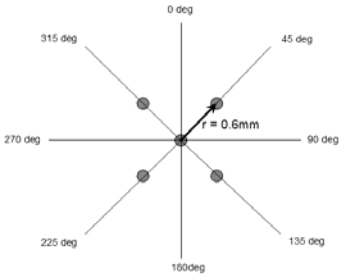


Figure 12. Schematic of 5 x 80µm orifice array.

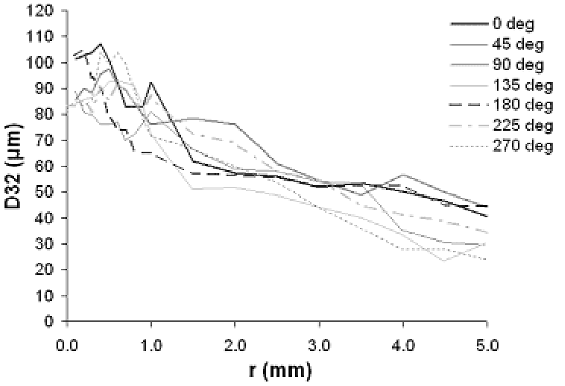


Figure 13. PDA results of SMD vs. radial position for a 5 x 80µm orifice array, with 100µm electrode gap 8kV applied voltage and 2bar gasoline supply.

Figure 14 shows the matching droplet axial velocity from the same set of PDA results as figure 13. Here the velocities of the larger droplets in the centre of the spray are again at approximately 20ms-1 whilst the smaller droplet velocities have dropped to virtually zero, with the exception of the velocities on the 90^{o} radial line which show a markedly high axial velocity. The reason for this discrepancy is not yet apparent.

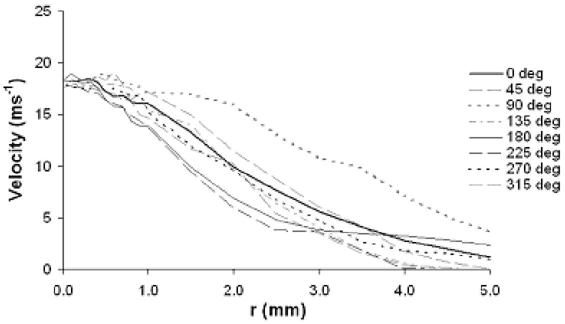


Figure 14. PDA results of Droplet Velocity vs. radial position for a 5 x 80µm orifice array, with 100µm electrode gap 8kV applied voltage and 2bar gasoline supply.

Although the overall atomization was good and largely consistent, some variations were observed through out testing that could only be put down to some internal and external influences such as ambient temperature, fuel blend and humidity etc. Internally the variations could also be caused by degradation of the electrode, through long term use or abuse, and dissociation of the fuel blend through Joule Heating, these issues are now the subject of a longer term investigation.

Mono-Size Droplet generation.

As well as highly atomized sprays it is possible to use this facetted planar electrode design for the generation of mono-sized droplets. With the application of a low level of electrostatic charge, a stream of dual size droplets are generated as shown in the images figure 15 and data in figure 16.

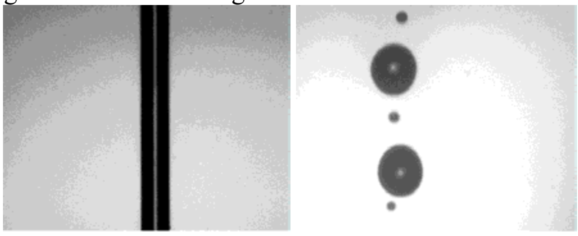
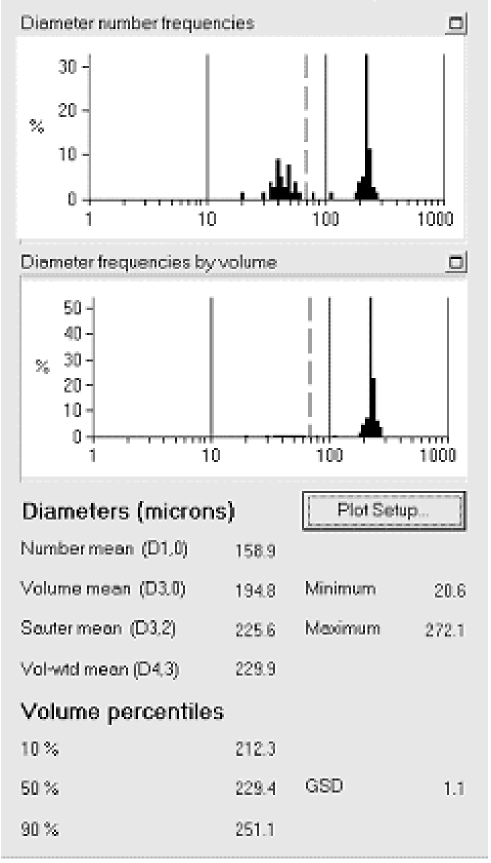


Figure 15. Fluid flow from a single 150µm orifice showing the difference between 0kV applied voltage and 5kV applied voltage, resulting in the dual-sized droplet generation.

Then with the simple addition of a surrounding steering and collection trap the smaller droplets are easily driven off due to the very large difference in relative droplet size and charge, as can be seen in figure 17, leaving just the larger mono-sized droplets to emerge from the spray nozzle.



Diameters (microns)

Number mean (D1,0)	158.9		
Volume mean (D3,0)	194.8	Minimum	20.6
Sauter mean (D3,2)	225.6	Maximum	272.1
Vol-wtd mean (D4,3)	229.9		

Volume percentiles

10 %	212.3		
50 %	229.4	GSD	1.1
90 %	251.1		

Figure 16. Drop size distribution of dual size droplets

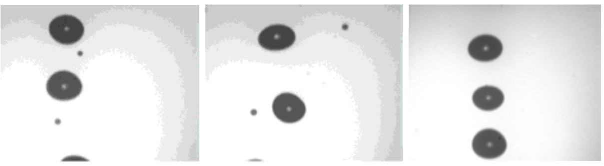


Figure 17. 3 images, each with increasing fluid charge, showing the effective displacement of the smaller droplets using a surrounding trap.

All of the mono-sized droplet experiments shown here were performed with a fluid mix of 50/50 Gasoline and Rape Seed Oil.

Conclusions

- Atomization of dielectric fluid can be achieved with a planer faceted electrode.
- An array of any number of orifices can be made to atomize fluid through the use of a single planer faceted emitting electrode.
- The axial positioning of the planer faceted electrode is not critical to achieve electrostatic atomization.
- Mono-Sized droplets can be produced and controlled using electrostatic sprays.
- The results produced at both laboratories correlated well with each other.
- These promising results have now allowed different application of electrostatic sprays to be explored, where either fine atomization or mono-sized droplets are required at high flow rates for dielectric fluids.

References

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[2] Shrimpton JS and Yule AJ, “Atomization, combustion and control of charged hydrocarbon sprays”, Atomization and Sprays, 11, pp. 1-32, 2001

[3] International Patent Application number WO2004/071670 A1

[4] Allen J and Ravenhill P, “A Novel Approach to Port Fuel Atomisation using a Very Low Power Multi-Holed Micro Atomiser” JSAE Paper number 20055436, 2005.