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163 A Novel Approach to Port Fuel Atomisation using a Very Low Power Multi-Holed Micro Atomiser.*

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Small gasoline IC engines worldwide are facing new emission legislations, manufactures are seeking low cost and low power consumption fuel control technologies to reduce their engine-out emissions. This paper presents details of the design of a novel multi-holed electrostatic port atomiser using an array of micron-sized orifices, achieving spray droplet diameters less than 40µm SMD, achieved with low pressure (<2.0bar) fuel systems and power consumption levels of only milliwatts. Results from research studies and development tests will demonstrate the atomisation capabilities of this electrostatic atomiser and its possible application to IC engines..

***Keywords*; Atomisation, Electrostatic, Emissions, Fuel Injection**

1 INTRODUCTION

New emission legislations on small engines are coming into force on a world wide basis. This will affect all small engines such as hand-held tools, stationary generators, off-road vehicles and equipment like lawnmowers, small tractors etc, as illustrated in Fig 1.

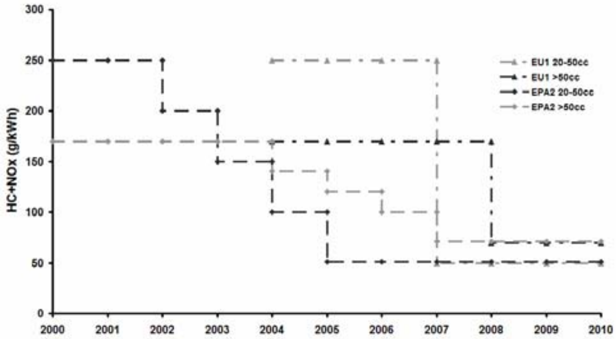

Figure 1 Emission Legislation Levels for Small Engines

There is a global production of some hundreds of millions of engines per year that will fall into this category that must meet these new emission standards now or in the very near future.

In many applications manufactures have already switched from 2-stroke to 4-stroke engines to achieve cleaner emissions, however most of these engines still use simple carburettors.

This market is extremely cost sensitive with many of the engines being single cylinder small capacity units, it is therefore vital that any technology added to the engines must achieve maximum emission benefit for the absolute minimum on-cost and minimum parasitic power consumption.

Work by several researchers [1,2] has shown that improved fuel atomisation will reduce emissions without the need for catalyst aftertreatment. Therefore, one proposed strategy to meet emission legislation is to improve the fuel delivery into the engine by increasing atomisation, distribution and air-fuel ratio control accuracy. However, the only readily available fuel control systems are Port Fuel Injection (PFI) and Direct Injection (DI), these having been developed through the automotive market tending to be complex, expensive and have very high parasitic power consumptions. These factors make them highly unsatisfactory for use on small single cylinder engines. The small engine industry is therefore urgently seeking fuel control systems that are low cost, deliver accurate, highly atomised fuel quantities, and are low on parasitic power losses.

This paper presents new research into one possible solution to this requirement, which is the use of electrostatic charge applied to the fuel to induce fine atomisation.

2 ELECTROSTATICS BACKGROUND

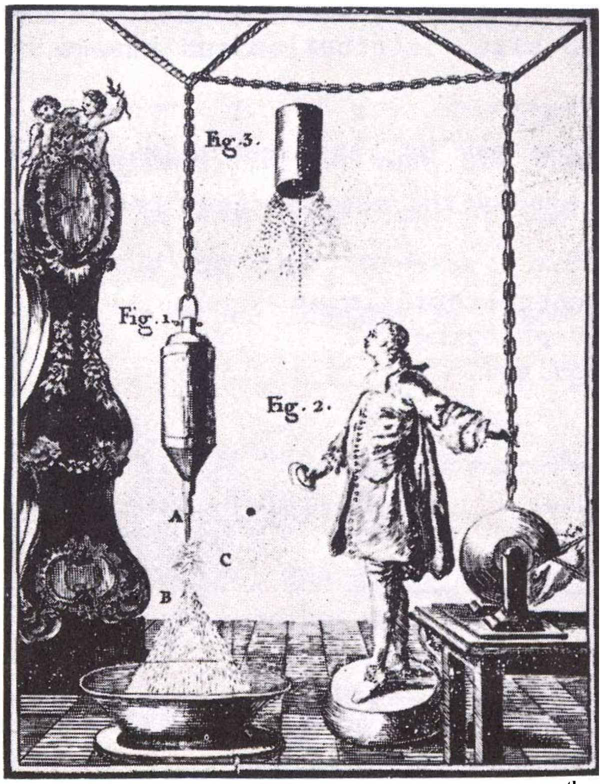

Figure 2. Electrostatic spraying of water in 18th Century by Abbe Nollet [3]

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The process of Electrostatic atomisation has been known since the 18th century with many experimenters working with water based fluids and hand powered high-voltage generators, as depicted in Fig. 2.

The basic process of atomisation is to overcome the surface tension forces thus making the surface of the liquid unstable so it will form into ligaments and then droplets. This is normally achieved by the application of mechanical or aerodynamic forces being applied to the fluid. However with electrostatic atomisation this disruption is achieved by the repulsive forces acting between like charges on the surface of the liquid. As the process is completely internal to the fluid, and no external mechanical or aerodynamic forces are required, break-up can be achieved with very small amounts of power.

The conventional configuration [4, 5, 6] for Electrostatic Atomisation when applied to dielectric fluids such as hydrocarbons, like gasoline or diesel, consists of a single sharp pointed electrode located above a single orifice, as shown in Fig. 3. The high voltage potential is applied between the pointed emitting electrode and the discharge orifice, hence a charge is transferred into the fluid as it passes the electrode and out of the orifice. It is this electrostatic charge in the fuel that induces its atomisation as it leaves the injector.

However in this arrangement the concentric alignment of the electrode and orifice is highly critical in order to achieve a uniform break-up of the complete liquid jet. Manufacturing tolerances of this critical dimension lead to practical limitations of orifice size and therefore result in restrictions on minimum droplet size. This combined with the flow restrictions of the single orifice design has limited electrostatic atomisers to small flow laboratory applications.

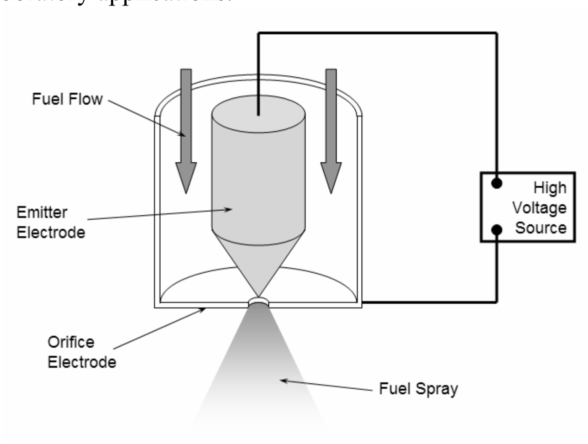

Figure 3 Sharp point Emitting electrode and single orifice atomiser

3 NOVEL FACETTED PLANER ELECTRODE

In order to overcome some of the restrictions of the sharp pointed electrode, single orifice arrangement of atomiser, a novel approach had to be taken. A facetted planar electrode is used that will work with a single orifice of any size with no requirement for concentric alignment. This new approach is also able to drive an array of multiple orifices from a single emitting electrode. Figure 4 shows the schematic arrangement of a multi holed atomiser.

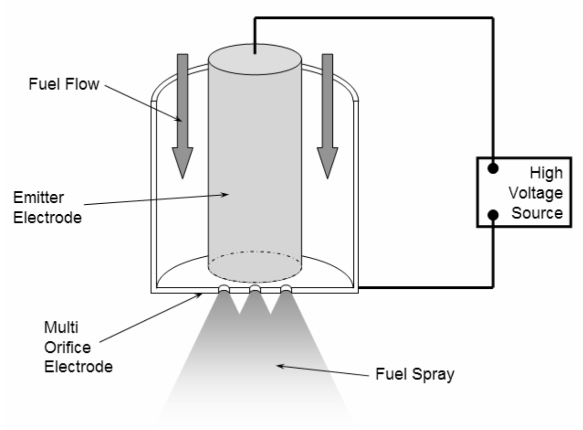

Figure 4 schematic of the planer electrode orifice arrangement

4 EXPERIMENTAL RESULTS

Experimental spray bench work has been carried out on the new atomiser configuration covering a range of different parameters. The study into the parameter relationships has allowed optimisation of the single orifice and the higher flow rate multiple orifice geometry. Further studies have allowed the testing of pulse width modulated atomisers suitable for engine applications.

The spray bench used for this parametric study, as shown in Fig. 5, comprises;

- a high voltage power supply and fuel delivery system, both feeding directly into the electrostatic atomiser,
- an image capturing system, based on a LaVision CCD Flowmaster camera with an exposure time of 100nsecs,
- a flash lamp unit with a fibre optic delivery cable and diffuser for back illumination,
- a fluid handling system that draws co-flowing air and atomised fuel into an air-fuel separator from where the air is extracted and liquid fuel drained.

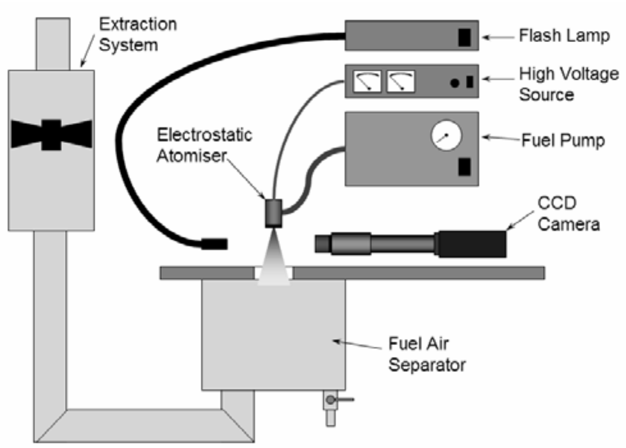

Figure 5, Spray Bench Schematic

Using a 105mm Nikon Macro lens and extension tube an image of 1.5mm x 1.2mm may be taken allowing the atomisation process to be captured in great detail, as shown in Fig. 6.

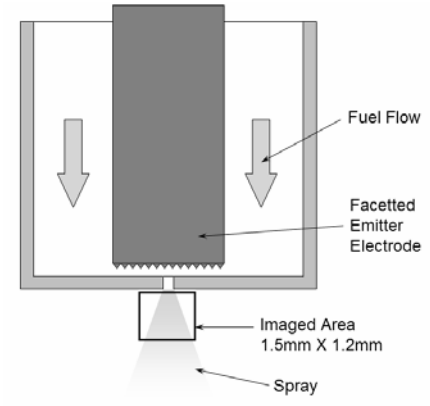

Figure 6, View of imaged area directly under atomiser discharge orifice.

Images like those in Fig 7b and 8b at different z distances below the orifice exit plane were captured on the spray bench and subsequently processed through Oxford Lasers VisiSolo software to calculate drop size distributions (including SMD, D_{10} etc) for the atomised spray. Using this measurement technique, parameters including orifice diameter (250µm to 50µm), orifice length, electrode gap, fuel pressure and applied voltage and current have been varied to determine their effect on atomisation of the fuel

Figure 7 shows images captured directly below the discharge orifice for a single 80µm orifice, image (a) is the fuel flow at 2bar pressure without any applied high voltage, image (b) is the same 2bar pressure but this time with an applied voltage of 4kV and current of 60µA, showing the effect of electrostatic atomisation.

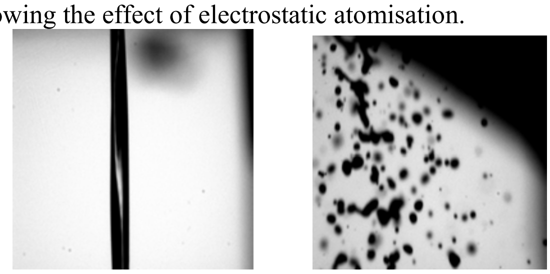

Figure 7, Fuel flow from a single 80µm orifice (a) 0kV applied, (b) 4kV 60µA applied

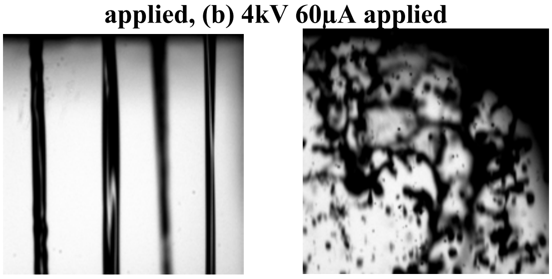

Figure 8, Fuel flow from 4x80µm orifice array (a) 0kV applied, (b) 6kV 40µA applied

Images shown in figure 8 are with the same lens and camera settings but this time the atomiser is a multi orifice configuration with 4x80µm orifices positioned at the corners of a 0.5mm square pattern. Again, image (a) shows the flow at 2bar fuel pressure with no voltage applied, and image (b) is the same pressure with 6kV applied.

The graph in Fig 11 shows the effect of increasing the applied voltage and current, expressed as power (Watts), on the drop size distribution, expressed as Sauter Mean Diameter (SMD) $D_{0.1}$, $D_{0.5}$ and $D_{0.9}$, measured at 15mm downstream from the orifice exit plane. The orifice is 80µm diameter and 160µm long, with a 95ULG fuel pressure of 1.5bar. The same experiment applied to a 4x80µm orifice array can also be seen visually in Fig 9. As the electrostatic power is applied the gasoline jet is disrupted into a spray, which continues to atomise further forming smaller droplets with increasing charge until an upper limit is reached where further charge input is lost to the surrounding air through corona discharge and no further effects on atomisation are seen.

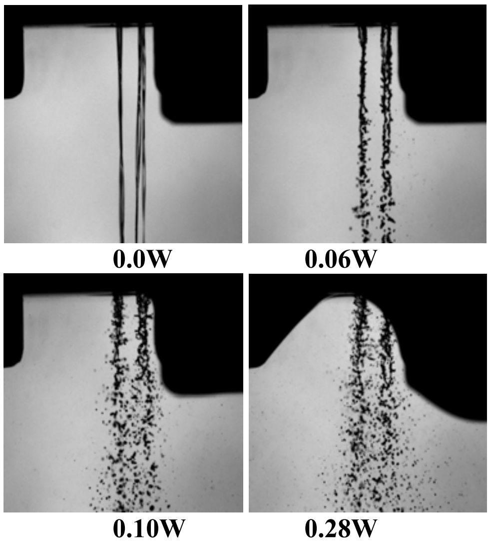

Figure 9, Visual images of the effect of increasing applied electrostatic power (Watts) on atomisation of gasoline at 2bar pressure from a 4x80µm orifice array.

The graph in Fig 12 shows the effect of varying the supply pressure of the fuel (95ULG) through a single 80µm orifice, and shows there is a good reduction in droplet size up to 2.0bar, achieving a SMD size below 40µm, while the effects above 2bar show a reduction in the droplet size range but no overall benefit to the SMD size. The graph also shows that the electrostatic process is functioning even at very low fuel pressures ≤0.5bar.

Another possible measure of an electrically charged spray is its Field Charge, here the measurement of electrical field strength is a measure of the charge carried by the droplets and their spatial dispersion. Fig 13 shows the effect of the gap between the facetted planer electrode and the orifice plate as a function of applied current for a range of gap settings. The single 80µm orifice is able to generate a well atomised spray over a wide range of electrode gaps indicating that manufacturing tolerances should not be a major issue, in making viable the design concept of a new injector. As can be seen in Fig 13 the field strength increases (negatively) as the current is increased until the onset of corona discharge where the field strength reduces to a steady condition were no further increase in current has any benefit.

Fig 14 is from the same experiment with SMD as the measured parameter with the same variation of applied current over the same range of electrode gaps. Again the stability of the atomisation process is evident over the wide gap range.

5 FURTHER WORK

From the bench test results it was concluded that a stable atomisation process was possible with conventional pump gasoline through an electrostatic atomiser at low fuel supply pressures. Using this system the total parasitic energy demand on the engine to achieve atomisation is small making it suitable for use in small engines. Further work is now underway to apply this concept to a 50cc engine using a pulse width modulated multi orifice electrostatic atomiser fitted into the inlet port, as shown in Fig 10. Table 1 shows the relationship between the engine size and number of 80µm diameter discharge orifices required to allow a pulse width modulated atomiser to flow sufficient fuel for full engine load at 8000rpm. The pulse width is based on inlet valve open time at 8000rpm.

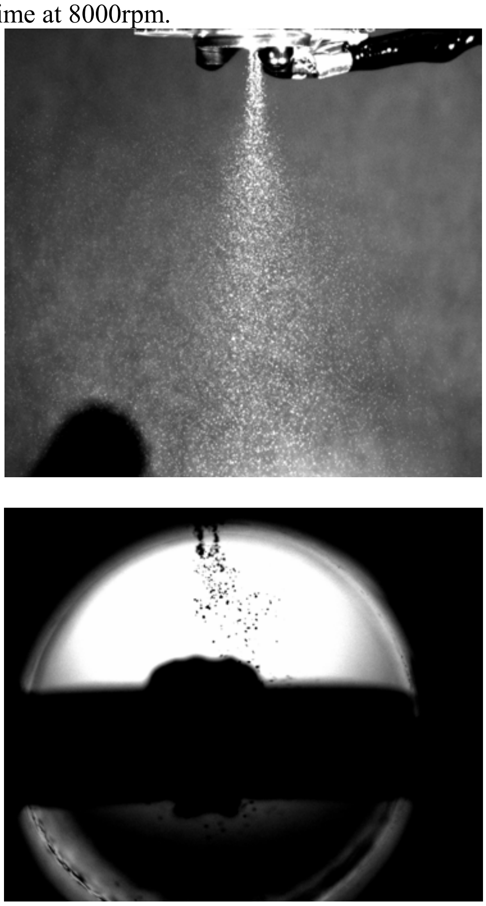

Figure 10, showing a spray bench electrostatic atomiser and the same atomiser fitted into the throttle body of a 50cc engine.

Engine Size cc	Injection Time msecs	Inj Fuel Mass mg/cycle	Array orifice size µm	Flow rate of single orifice mg/msecs	Number of Orifices
25	4.125	2.40909	80	0.073	8
50	4.125	4.81818	80	0.073	16
100	4.125	9.63636	80	0.073	32

Table 1, Engine size effect on number of orifices required to flow full load fuel requirement

6 CONCLUSIONS

The adoption of the facetted planer electrode enables multi orifice arrays to atomise fuel from a single electrode. Therefore atomisation of standard pump gasoline is possible at the required flow rates for I.C. engines with such an electrostatic process.

The internal geometries of the atomisers with planer electrodes are not as sensitive to manufacturing tolerances as the traditional single point electrode, thus allowing the possible use of low cost manufacturing processes.

The total parasitic power demand for the electrostatic atomiser is small, with only low fuel pressure and very small electrical power (<0.3Watts) being required.

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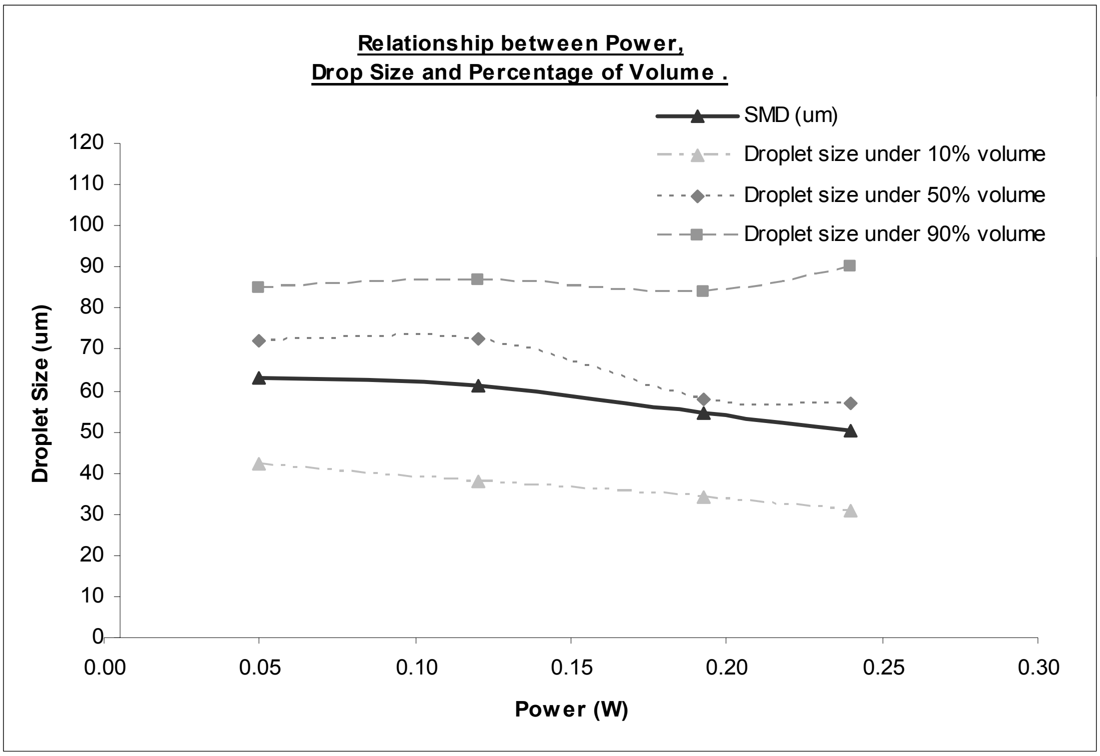

Figure 11, Effect of applied electrostatic power (watts) on atomisation of gasoline at 1.5bar pressure measured at z=15mm.

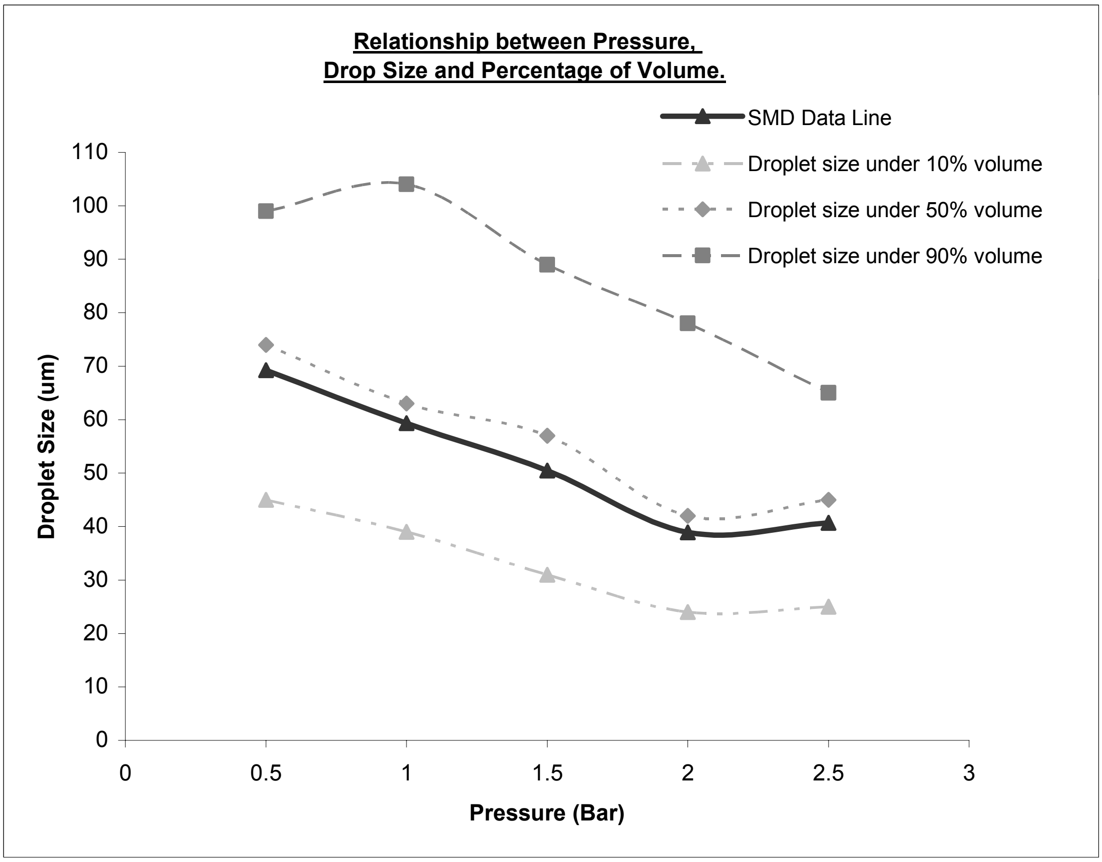

Figure 12, Effect of fuel pressure on atomisation from a single 80µm orifice measured at z=15mm.

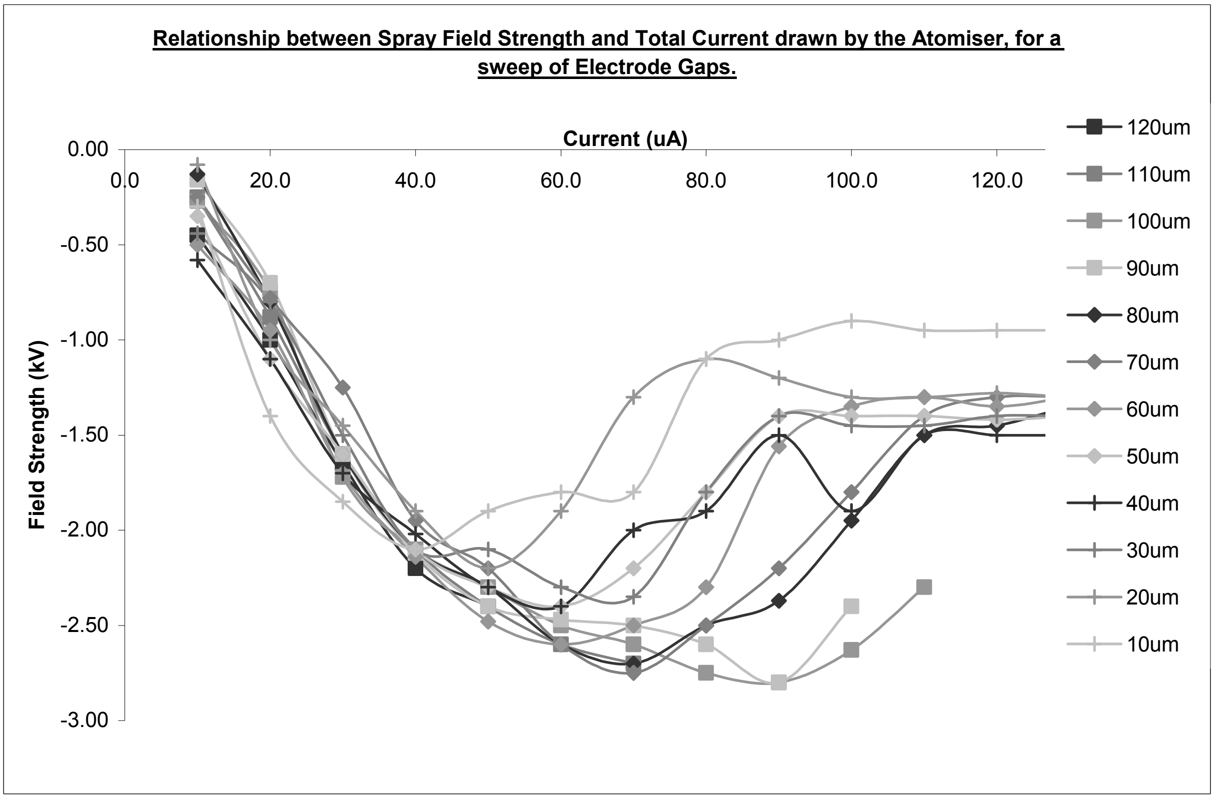

Figure 13, Effect of varying applied current on field strength over a range of different electrode gap settings from 120μm to 10μm.

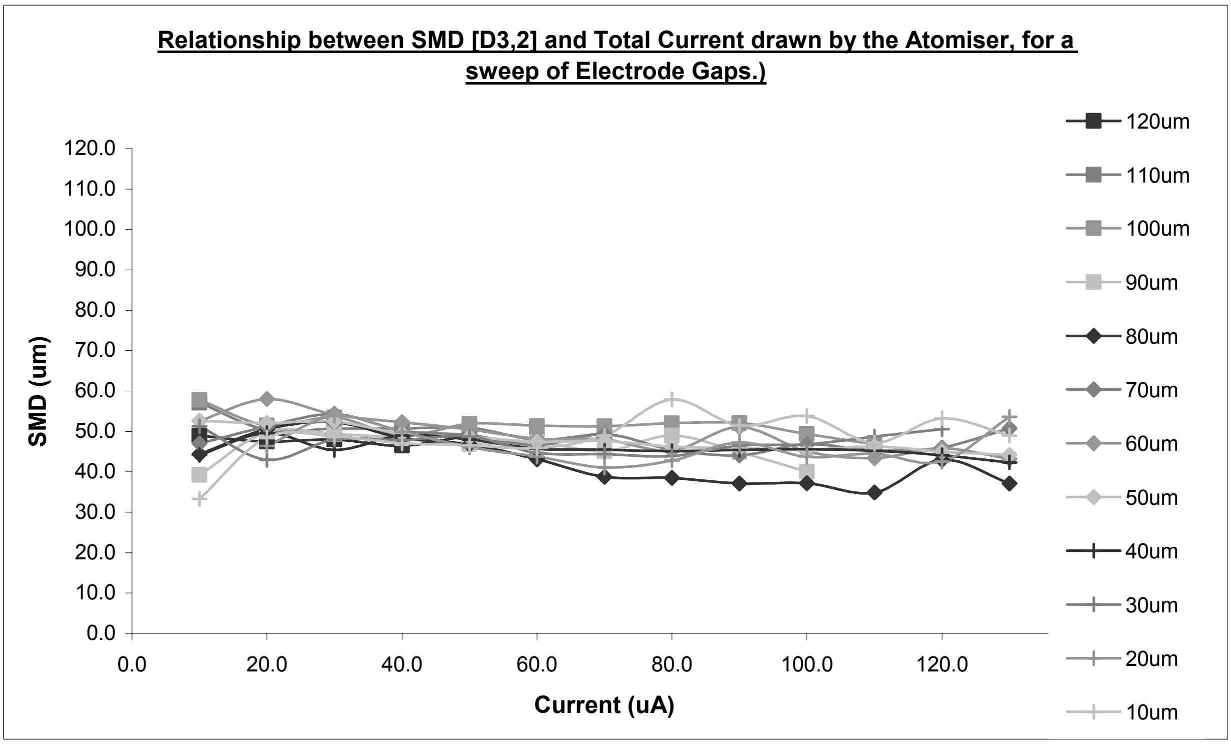

Figure 14, Effect of varying applied current on droplet size (SMD) over a range of different electrode gap settings from 120μm to 10μm.