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Droplets generated from a new 'ogee' shaped, liquid, air-shear, electrostatic nozzle

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ABSTRACT

A series of experimental tests was carried out on an 'OGEE' shaped planform, liquid air-shear electrostatic nozzle. Liquid was ejected from the upper surface of the nozzle and was then dispersed and atomized efficiently by a high speed air flow passing over the nozzle and by the effect of two very strong coherent air vortices generated by the 'OGEE' shaped nozzle surface. Initial test results which are presented in the paper show the nozzle to perform far superior to a similar delta wing shaped nozzle design which is used extensively in various industrial applications.

INTRODUCTION

The air shear nozzle is used in many spray applications which require relatively large quantities of finely atomized liquid droplets. It consists of an orifice which introduces a liquid into a high velocity air stream. The atomization results from the mechanical disruption of the liquid stream by the air shear and pressure forces[1]. A number of different geometries have been used for the nozzle ranging from simple open tubes to aerodynamically shaped nozzles. One commonly used geometry is a delta wing shaped planform nozzle with a raised lip along its trailing edge (See Figure 1.) In a previous investigation[2] the atomization pattern of this nozzle was studied in order to optimize the positioning of an induction electrode for electrostatic charging of the droplets. In the course of this investigation it was discovered that contrary to expectations, the majority of the atomization took place off the open surface of the nozzle rather than the raised lip. This observation led to further experimentation to determine the influence of the aerodynamic shape on the effectiveness of atomization. It led to the development of the new OGEE shaped liquid air shear nozzle shown in Fig. 2 (Patent Pending). In what follows a description of the theory of operation along with experimental results are presented for both the delta wing and OGEE nozzles with and without electrostatic charging.

AIR FLOW CHARACTERISTICS AS APPLIED TO AIR SHEAR NOZZLE DESIGN

The OGEE air shear nozzle, as shown in Fig. 2, has a slender wing airfoil planform shape. The particular shape used is called an 'OGEE' wing according to the resemblance to a leading edge of a wave like form similar to the letter 's'. The characteristics of slender wings are well described by Hoerner[3]. The essential flow regime generated by a slender wing at an angle of incidence to the approaching flow consists of two, strong, coherent vortices circulating with opposite rotational sense. These vortices start at the apex of the nozzle and are continually shed from the sharp 's' shaped leading edge to proceed downstream and pass over the trailing edge. The two vortices pass over the trailing edge of the nozzle at a position ranging from 90% to 70% of the semi span measured from the nozzle centre line. This depends on the angle of incidence and the ratio of the semi span to the length. The height of the vortex cores above the wing increases with an increase in the angle of incidence. In the design of an air-shear nozzle the angle of incidence and span to length ratio has to be chosen such that the vortices shed from the leading edge have a trajectory passing near the region where liquid will be released into the flow. One advantage of using a slender wing shaped nozzle instead of a more conventional straight wing of higher aspect ratio is that in the case of a slender wing the coherent vortex pattern is fully developed before the flow reaches the trailing edge whereas for a straight wing, the flow is not fully developed until at least several wing spans downstream of the trailing edge. In the final design, the vortices pass over the upper surface of the nozzle and increase the divergence of the liquid flow emitted from the upper surface. The effect of the two vortices also creates a very low pressure or high suction which improves the liquid flow and droplet atomization. The effect of the circulation and rotation of the vortices also improves the mass transfer of the liquid droplets after the two-phase flow has passed downstream of the trailing edge of the nozzle. A physical advantage of the 'OGEE' shaped planform nozzle compared with the delta wing shaped nozzle is that geometrically a larger liquid jet can be achieved for the same length, span and thickness of nozzle.

INDUCTION CHARGING WITH AIR SHEAR NOZZLES

The geometry of the air shear nozzle described above is ideally suited for induction charging since the atomization takes place over the open face of the nozzle. Thus by placing an insulated plane electrode opposite the nozzle face and by ensuring that the liquid has adequate conductivity and is connected to ground, induction charging of the droplets will take place at the moment of atomization. The advantages of combining electrostatic charging in droplet spraying are well known[4] and when compared with simple mechanical atomization include:

1. The production of smaller more uniformly sized droplets, since electrostatic surface charge counteracts surface tension forces,

2. More uniformly dispersed droplets on account of the mutual repulsion caused by their like charges,

3. More effective deposition of the charged droplets on target surfaces, due to the attraction by induced space charge image.

In the previous work with the delta wing shaped nozzle[2] the size and shape of the induction electrode was investigated along with the value of optimum induction field to maximize the charge to mass ratios.

EXPERIMENTAL RESULTS

The experiments were carried out using a commercially available air blast sprayer of the Kinkelder type as used in agricultural spraying. For the purpose of these tests, the spray heads were modified to allow induction charging[4]. This modification consisted of replacing the cast aluminum spray heads with identically shaped fibreglass heads having conductive induction electrodes embedded flush with the inside surface at points opposite the air shear nozzles. The electrodes were connected via an imbedded high voltage cable to a self regulating H.V. power supply rated 15 kV open circuit. The power supply was fed from a 12 V DC battery. The complete spray system is shown in Fig. 3. With this arrangement it was possible to test the air shear nozzles under fixed conditions with the only difference being the presence or absence of induction charging (i.e.: induction voltage switched on or off).

Figure 4 shows an example of the type of atomization produced with a single OGEE nozzle mounted in the spray head. This photograph illustrates the back flow of liquid caused by the vortices induced by the OGEE nozzle and the resulting atomization. Normally five nozzles were mounted in the head during the tests.

The droplets were sampled using microscope slides coated with viscous polybutene. The slides were mounted behind a mechanical shutter having a 1 cm diameter opening. This allowed the slide to be exposed to the cloud of droplets for brief exposures ($\approx$ 0.5 second). The viscous polybutene trapped the droplets intact and when covered with a slide cover immediately after sampling, allowed particle analysis to be done up to 2 or 3 days after the test without any change in the sample. The particles were counted and sized manually using a microscope equipped with a squared graticule.

The spray pattern was sampled with the shutter mounted at a right angle to the spray flow at a distance of 3 m from the heads. Droplet charges were measured by collecting samples of the spray in a shielded metallic container connected as a Faraday pail. Thus by measuring the accumulated charge for a given mass of droplets, the average charge to mass ratio was calculated.

Table I, gives a summary of the results obtained for one set of conditions. A similar pattern of results was found for different flow rates for both the liquid feed and the entrainment air.

TABLE 1

RESULTS OF TESTS ON THE 'OGEE' SHAPED PLASTIC NOZZLE AND A DELTA WING SHAPED METAL NOZZLE

	'OGEE' Shaped Plastic Nozzle		Delta Wing Metal Nozzle	
	Voltage 'On'	Voltage 'Off'	Voltage 'On'	Voltage 'Off'
Mean diameter of droplet (μm)	51	61	69	70
Standard deviation of diameters measured (μm)	37	32	48	61
Charge to mass ratio (μC/g)	6.2	N/A	5.8	N/A
Air speed (m/s)	85	85	85	85

liquid flow rate = 10^{-2} kg/s/nozzle

DISCUSSION

One of the most significant findings in the course of this development was the observed backflow of the liquid over the top surface of the OGEE nozzle. The flow visualization studies clearly showed that when the liquid emerged from the upper surface of the nozzle the initial motion was upstream due to the separated flow near the centre of the nozzle. This greatly improved the mechanical atomization of the liquid since it was more readily entrained by the two strong coherent vortices. In addition, the upstream motion produced a larger area of atomization giving better exposure to the inducing electric field for the combined mechanical-electrostatic atomization.

As seen from Table I, the OGEE generated droplets offered considerable improvement over the delta wing nozzle. Comparing the two conditions i.e. with and without electrostatic charging it is seen that:

a) the droplets generated with the OGEE are smaller in diameter; 13% in the case of pure mechanical atomization, 26% in the case of mechanical-electrostatic atomization.

b) the droplets generated with the OGEE are more uniform; the standard deviation is 48% smaller in the case of mechanical atomization, 23% smaller in the case of mechanical-electrostatic atomization.

c) the number of droplets generated with the OGEE is greater: considering that the liquid flow rates were the same in all cases and that mass is proportional to the cube of diameter the average number of OGEE generated drops is 147% greater than the delta generated drops for the mechanical atomization, and 245% greater for the mechanical-electrostatic atomization.

d) the mechanical-electrostatic atomization produced in the OGEE nozzle is superior to all other conditions in terms of minimum particle size, uniformity of particle size, maximum number of droplets for a given liquid flow rate and charge to mass ratio.

CONCLUSIONS

Due to the improved atomization it it believed that the new nozzle described here will have superior characteristrics for both industrial and agricultural applications where large concentrations of reasonably uniform, small sized droplets are required. Also being an air shear nozzle it retains the advantages of having a relatively large diameter clog free feed allowing substantial liquid flow rates.

ACKNOWLEDGEMENTS

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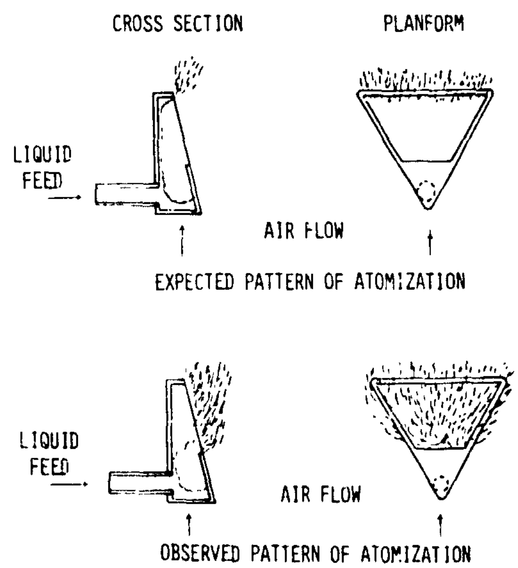

FIGURE 1. DELTA WING SHAPED AIR SHEAR NOZZLE

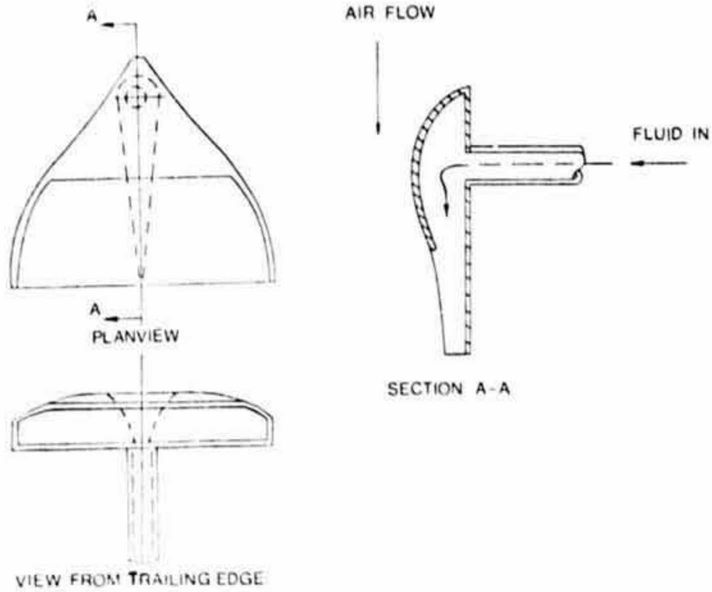

FIGURE 2. THE OGEE AIR SHEAR NOZZLE.

FIGURE 4. LIQUID ATOMIZATION FROM A SINGLE OGEE NOZZLE MOUNTED IN THE SPRAY HEAD (ENTRAINMENT AIR VELOCITY 85 M/S).

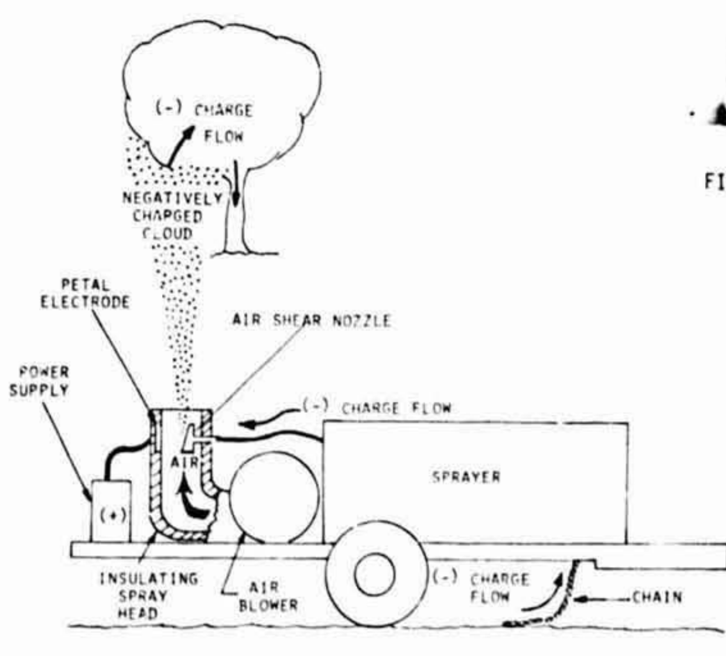

FIGURE 3. THE ELECTROSTATIC SPRAY SYSTEM.