EPA/AA/TDG/93-05

Technical Report

Spray Characteristics of Two Types of Fuel Injectors

by

Jeffrey P. Hahn
Fakhri J. Hamady
Karl H. Hellman

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U. S. Environmental Protection Agency
Office of Air and Radiation
Office of Mobile Sources
Regulatory Programs and Technology Division
Technology Development Group
2565 Plymouth Road
Ann Arbor, MI 48105

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
ANN ARBOR, MICHIGAN 48105

APR 2 1989

OFFICE OF
AIR AND RADIATION

MEMORANDUM

SUBJECT: Exemption From Peer and Administrative Review

FROM: Karl H. Hellman, Chief KH
Technology Development Group

TO: Charles L. Gray, Jr., Director
Regulatory Programs and Technology Division

The attached report entitled "Spray Characteristics of Two Types of Fuel Injectors," (EPA/AA/TDG/93-05) describes the results of our continuing in-house study of fuel injector properties. A laser diffraction technique was used to quantify the fuel spray droplet sizes and volume concentration for two different types of fuel injectors.

Since this report is concerned only with the presentation of data and its analysis, and does not involve matters of policy or regulations, your concurrence is requested to waive administrative review according to the policy outlined in your directive of April 22, 1982.

Concurrence:

Charles L. Gray, Jr., Director, RPT Date: 4-1-93

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I. Introduction

The Technology Development Group (TDG) of the Regulatory Programs and Technology at the EPA National Vehicle and Fuel Emissions Laboratory (NVFEL) has evaluated the spray characteristics of two types of fuel injectors intended for possible application in alcohol-fueled automotive engines. This report is part of TDG's ongoing research program on time resolved spray analysis and combustion processes utilizing high-speed flow visualization and laser diffraction techniques. The two types of injectors which were studied are a standard gasoline pintle-type port fuel injector and an air-assist poppet valve injector previously developed at NVFEL, which is based on an injector used in a swirl chamber Diesel engine. Nitrogen is used as an atomizing fluid rather than air in this work. The spray analyses were performed using a Malvern Series 2600 particle size analyzer.[1] This analyzer is used to measure the particle size distribution and volume concentration of liquid droplet sprays. The measurements were taken as the injectors were injecting into the atmosphere at different fuel injection pressures. Experimental results showed that the air-assist poppet valve injector generated finer particles compared with the pintle-type injector.

II. Spray Measurements

The Malvern Series 2600 Laser Diffraction System is a non-intrusive optical measurement instrument used to characterize liquid or solid particles. A detailed description of the Malvern system is included in Appendix A. Due to the periodic nature of the fuel injector events, a Malvern PS51 pulsed spray synchronizer [2] was used to control both the fuel injection and measurement timing for the experiment. The synchronizer controls the injection period and duration and also sends a delayed trigger signal to the measurement unit relative to the beginning of the injection event which ensures that the actual particle size measurement occurs when the fuel spray intercepts the measurement region. A dynamic output mode of the Malvern system allows the user to determine the appropriate trigger delay for the given injector location.

III. Fuel Injectors

The port injector used in this study is a Nippondenso pintle-type injector which is used in Nissan products (see Figure 1). This injector was operated in its stock configuration at a fuel injection pressure of 50 psi. The test fuel was methanol.

The air-assist poppet valve injector is a modified Lucas Microjector (see Figure 2). The Lucas Microjector is a direct injection Diesel injector with an outwardly opening poppet which was used in the U.S. market in some GM passenger car swirl chamber

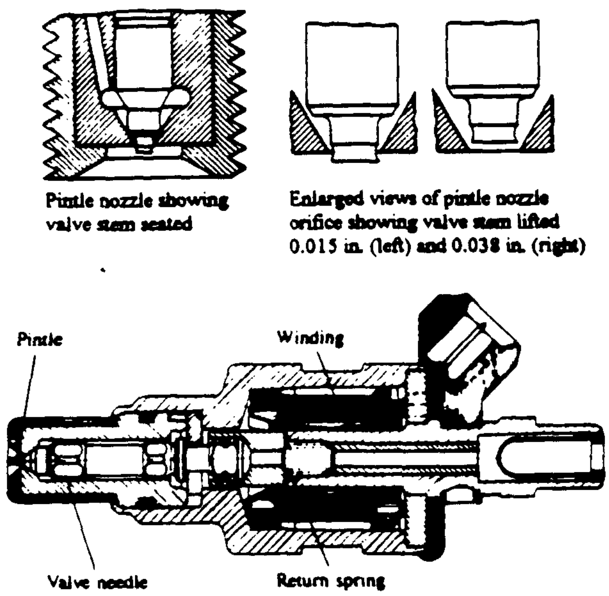


Figure 1 Cross section of pintle type fuel injector

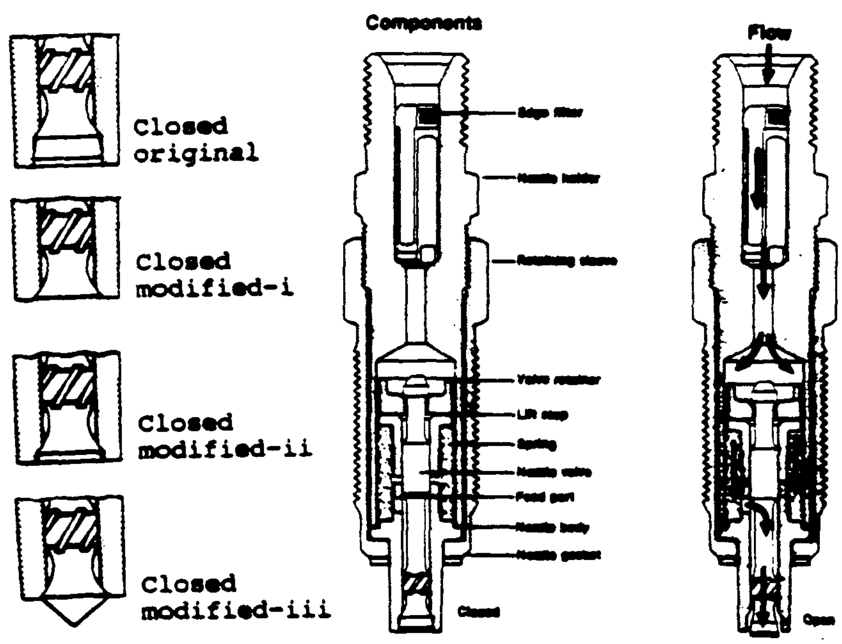


Figure 2 Cross section of poppet type fuel injector

Diesels. The Microjector poppet and nozzle body were modified to provide a wider spray angle for this injector. The modifications also resulted in less wetted surface area downstream of the valve seat in the nozzle body which should reduce the injected droplet size. Three separate poppet valve and nozzle body combinations were used in the tests. Nitrogen was used rather than air for the atomizing process and the injected fuel was methanol. The nitrogen and methanol were metered to the Microjector through individual pintle injectors mounted on a yoke upstream of the Microjector. The nozzle spring was modified for this experiment to allow the injector poppet valve to open at lower pressures than it would in its stock configuration for Diesel applications. The air-assist poppet valve injector was operated at pressures of 75, 100, and 135 psi in order to evaluate the effects of fuel pressure on the spray characteristics.

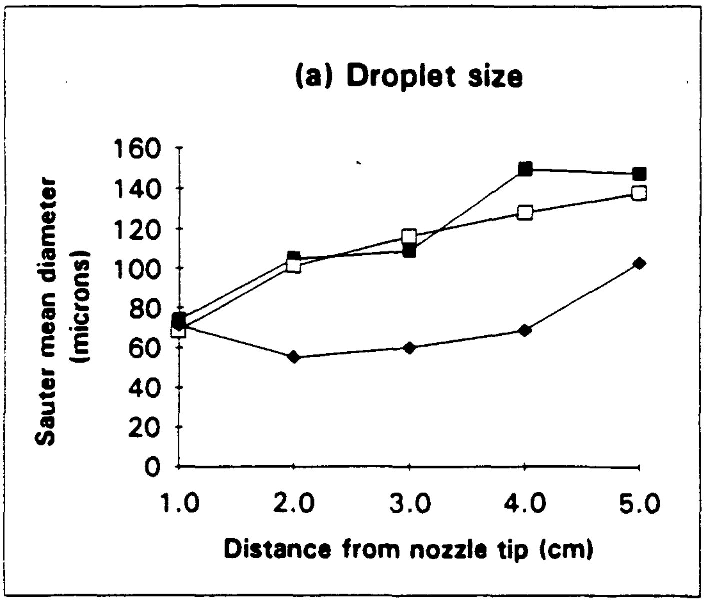
IV. Characterization of the Liquid Fuel Spray

This section presents the fuel spray characteristics of methanol fuel injected into the atmosphere with the following injector configurations:

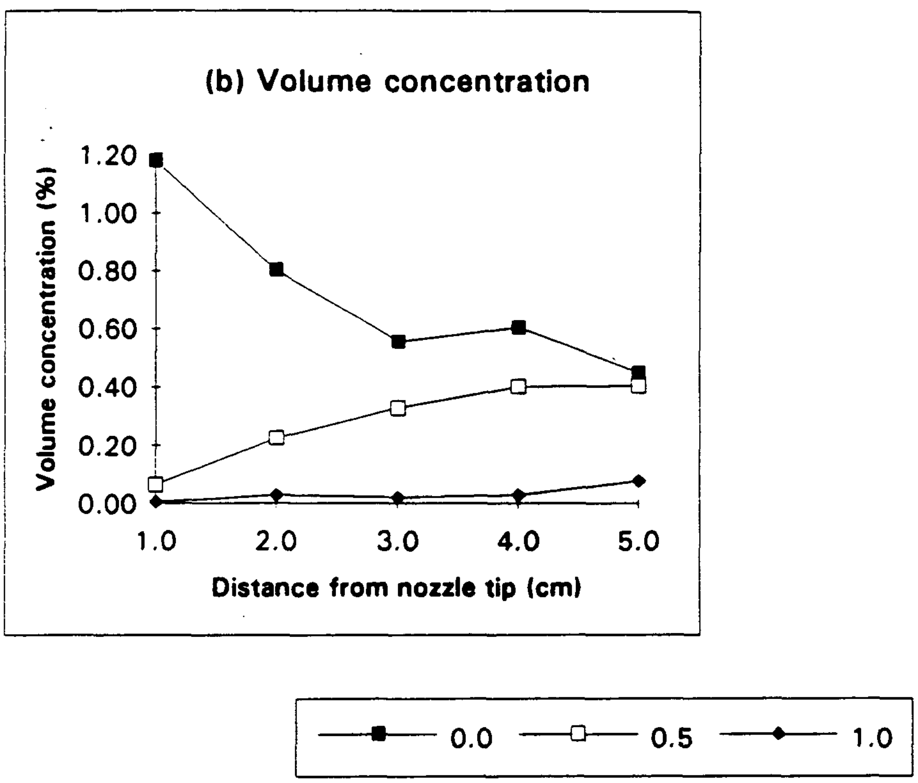
- Pintle injector @ 50 psi
- Air-assist injector with modified i poppet @ 135 psi
- Air-assist injector with modified ii poppet @ 135 psi
- Air-assist injector with modified iii poppet @ 135 psi
- Air-assist injector with modified iii poppet @ 100 psi
- Air-assist injector with modified iii poppet @ 75 psi

All practical sprays are comprised of drops of a variety of sizes. There are many different ways in which the droplet size distribution can be characterized. One way in which a spray can be characterized is by use of the Sauter Mean Diameter (SMD). The SMD is the diameter of a drop that has the same surface-to-volume ratio as the entire spray. The SMD has been found to be a very useful indicator of the nature of a fuel spray for engine work and is the measure we have chosen to use in this report.

The axial distributions of the SMD and volume concentration from a pintle injector fuel spray are presented in Figure 3. Data is shown for three different radial sections offset from the spray centerline at an injection pressure of 50 psi. The profiles in Figure 3(a) along the centerline downstream of the pintle nozzle show an increase in the droplet size as the distance from the nozzle increases. We attribute this behavior to the separated back flow generated at the pintle valve and the counter rotating vortical structure which proceeds downstream to cause droplets to coalesce. This phenomenon is due to the dissipating energy of the liquid jet caused by the vortical structure which dominates along the spray centerline. Smaller droplets are found at the spray periphery because of the higher liquid jet momentum which breaks the liquid stream into smaller droplets.



Sprays from a pintle nozzle



Offset from spray centerline (cm)

Figure 3 - Droplet size and volume concentration for pintle injector at 50 psi fuel injection pressure

Figure 3(b) presents the axial distribution of volume concentration for the pintle injector at 50 psi. The profiles indicate that the volume concentration is greatest along the spray centerline; therefore, the concentration of large particles in the spray is very high.

The SMD and volume concentration for an air-assist poppet valve injector at an injection pressure of 135 psi are shown in Figure 4. The profiles in Figure 4(a) indicate that the smallest droplets are found along the spray centerline. As expected, this is attributed to the high atomization of the higher air jet momentum along the centerline which breaks the fuel stream into smaller droplets. At the spray periphery near the nozzle/poppet valve region, larger droplets are found due to fuel nozzle surface interactions and droplet coalescence.

Figure 4(b) illustrates that the volume concentration at the centerline of the air-assist injector spray is the greatest. The profiles indicate that small droplets are most prevalent in the air-assist injector's spray.

The effects of injector pressure on the SMD of the air-assist injector are shown in Figure 5. It is apparent from this figure that the increase in injection pressure enhances the atomization of the fuel spray. Fewer data points are shown in Figures 5(c) and 5(d) because of the high extinction rate which prevented drop size determination outside of the spray cone.

Spray droplet sizes for different nozzle/poppet valve configurations with the air-assist injector are shown in Figure 6. The nozzle/poppet valve configurations which were used are shown in Figure 2. The results show that configurations with flat poppet valves (modified i and ii) yielded slightly better performance than did the pointed poppet valve (modified iii).

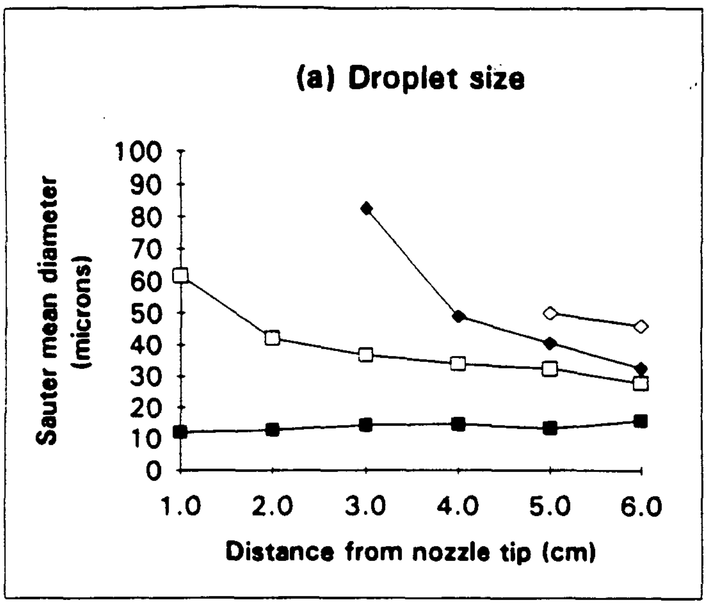
V. Summary

Spray characteristics of pintle and poppet valve injectors injected into the atmosphere have been measured using laser diffraction measurements. Comparison of the spray results at different fuel injection pressure and nozzle/poppet valve configurations provided useful information on the controlling parameters of the sprays. The following insights can be made:

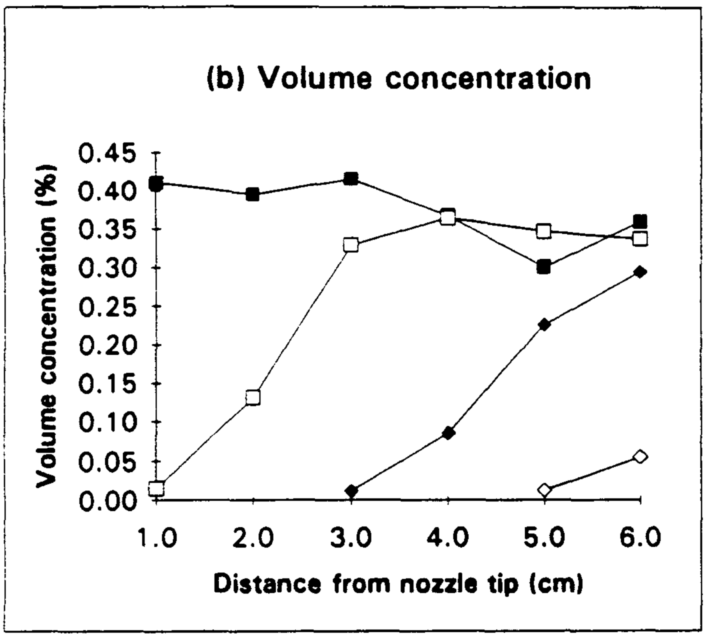
1. The presence of atomizing air (nitrogen is used in this study) has a significant effect on the spray characteristics.

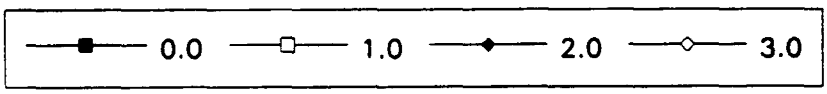
2. The mean droplet size for the pintle injector is larger than that from the air-assist poppet valve injector.

3. Spray characteristics for the two types of injectors are dependent on fuel injection pressure and nozzle/poppet valve configurations. Mean droplet size decreases with increasing injection pressure.



Sprays from a nozzle with poppet valve





Offset from injector axis (cm)

Figure 4 - Droplet size and volume concentration for an air-assist injector with modified iii poppet valve at 135 psi Fuel injection pressure

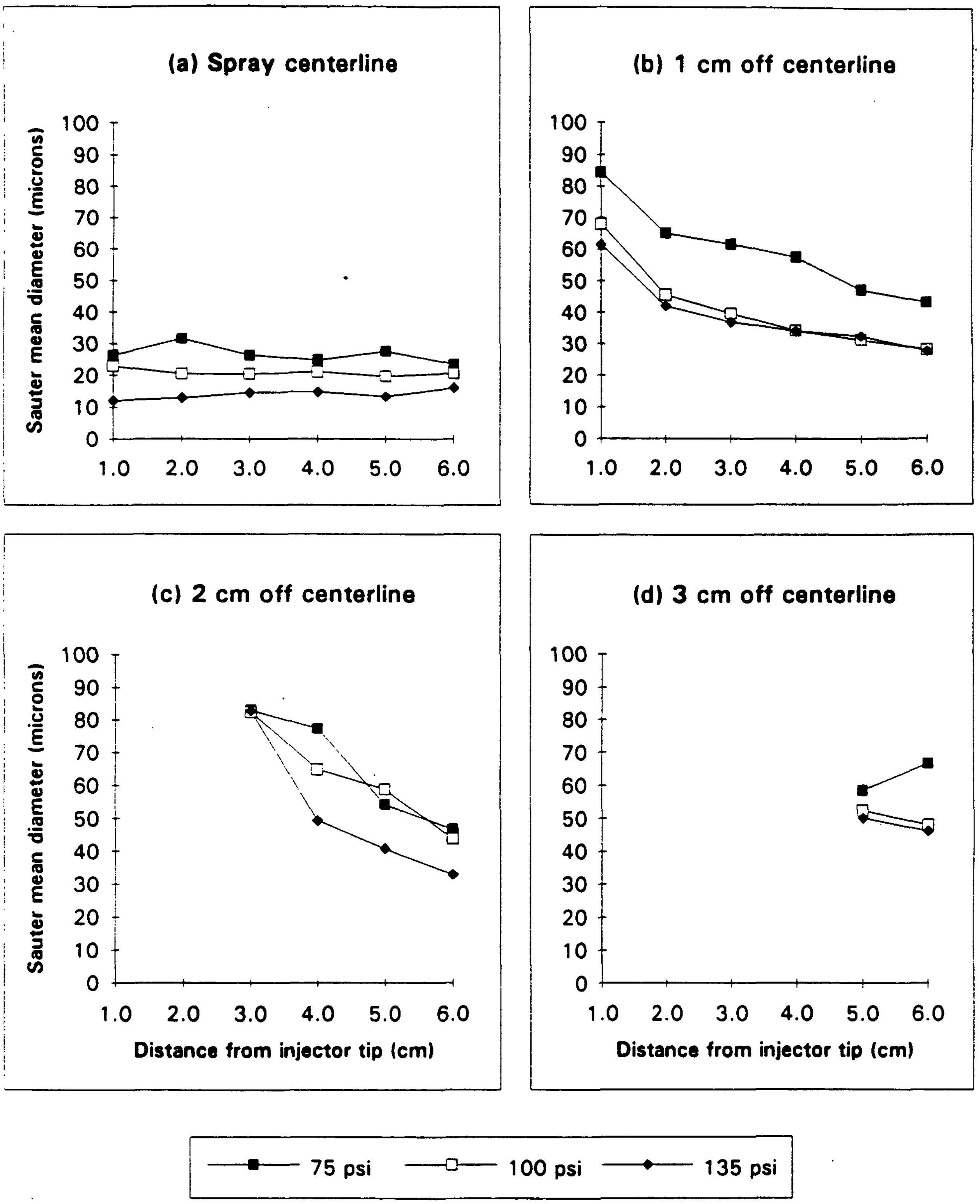


Figure 5 - Effect of injection pressure on spray droplet size for an air-assist poppet valve injector

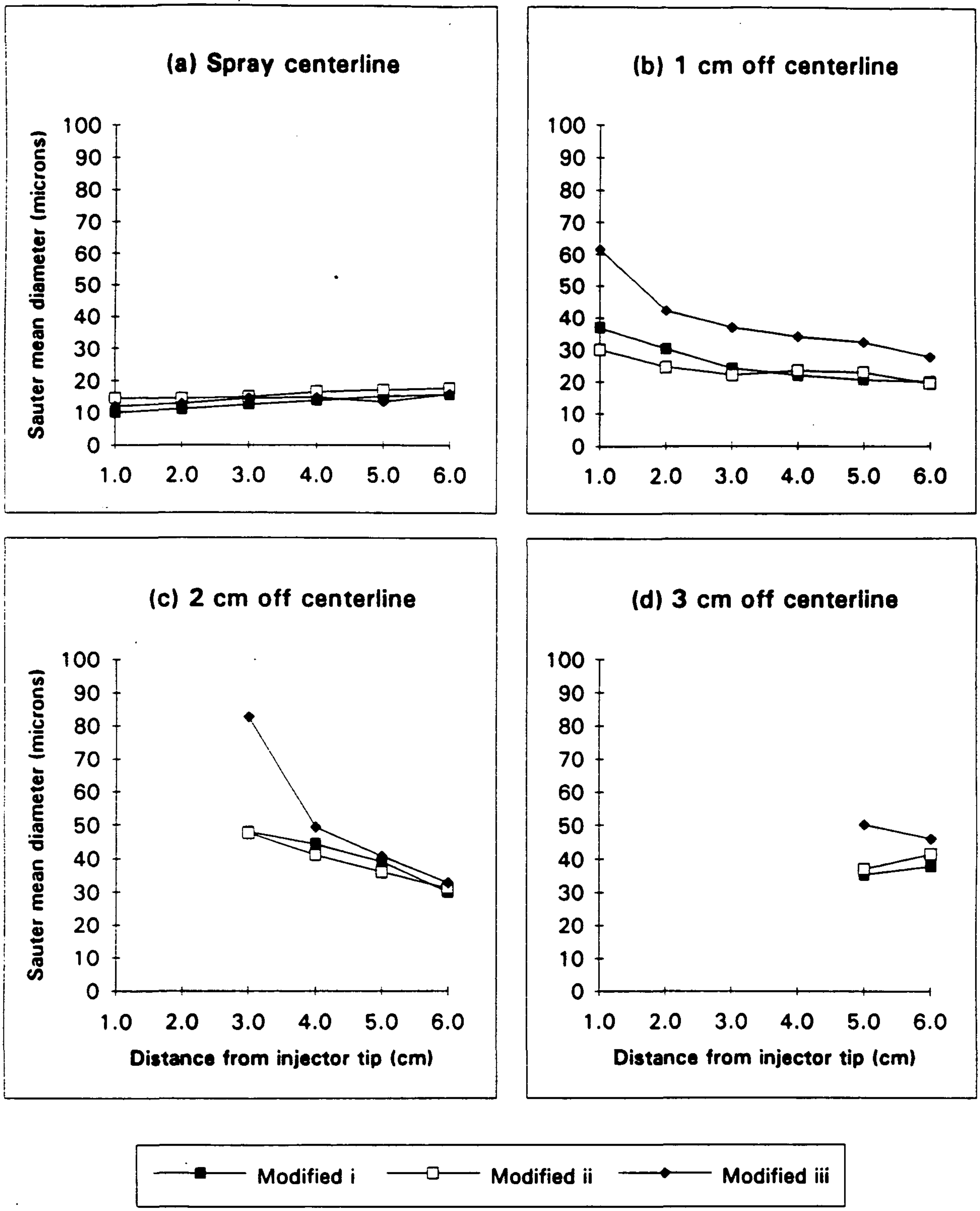


Figure 6 - Effect of nozzle/poppet valve configurations on spray droplet size from an air-assist injector at 135 psi fuel injection pressure

4. The air-assist poppet valve injectors have a higher concentration of relatively small particles in their sprays than does the pintle valve injector.

VI. Future Directions

As the demand for higher performance and lower emissions from automotive engines is concentrated more on the combustion chamber, our future efforts will focus on time resolved spray analysis and combustion processes in an engine assembly. New concepts and technology will be tested using both high-speed flow visualization and laser diffraction techniques. Data will be incorporated in automotive engine developments to promote clean combustion and reduced emissions for future generation engines.

VII. Acknowledgments

The authors appreciate the efforts of Philip Dingle of Lucas Automotive for providing the injectors to modify and also for advice on how to modify the injectors. The authors also recognize the efforts of Jennifer Criss for word processing and editing support.

VIII. References

1. Malvern Instruments 2600 Series - User Manual.

2. Malvern Instruments Pulsed Spray Accessories.

Appendix A

Malvern Series 2600 Particle Sizer

The Malvern Series 2600 laser diffraction particle sizer is an optical system that can be used for particle size analysis of powders, aerosols and sprays. This system consists of a 2 mW He-Ne laser (633nm wavelength) with a 9mm diameter beam, transmitter and scanning receiver mounted on the opposite sides of an optical bench. The transmitter and receiver are interfaced to an IBM- compatible personal computer. The receiver is equipped with a Fourier transform lens of 300 mm focal length to focus on a semi-circular concentric diode array detector (31 diodes). The signal from each detector diode proportional to the intensity of light falling on it is amplified and digitized and transferred to the controlling computer, where it is analyzed.

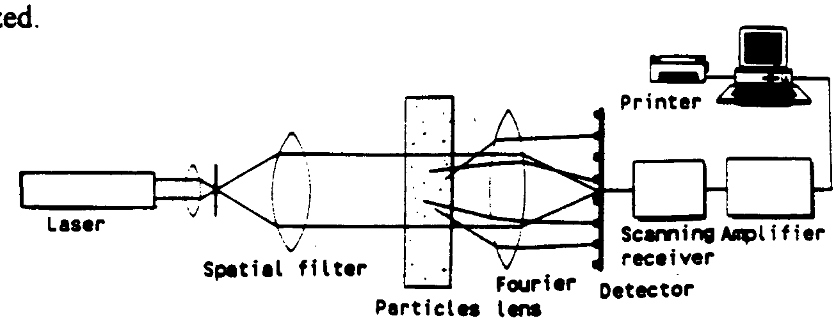


Diagram of System Configuration

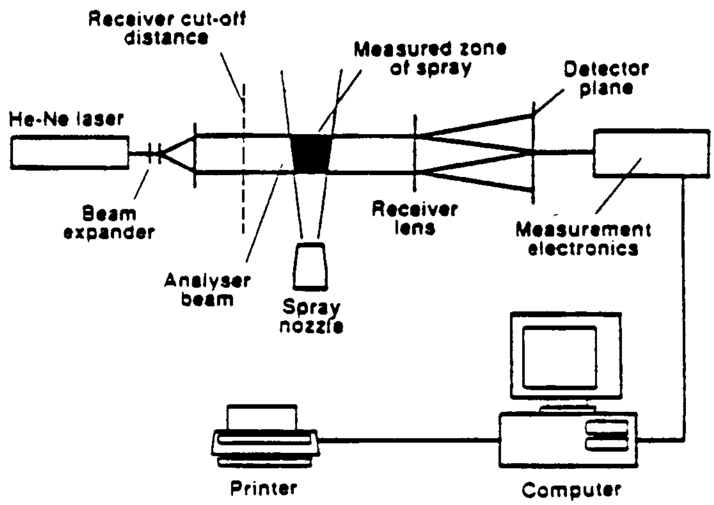


Diagram of Laser Diffraction Experiment

The initial output consists of light energy detected by each diode, arranged in a histogram from the innermost to the outermost diode, as well as overall beam intensity and obscuration. The Malvern software can provide calculated information such as the Sauter mean diameter (SMD) and other derived parameters including volume concentration and specific surface area. The particle size distribution can also be presented in a variety of graphical and tabular results formats.

For our work with the fuel injectors, the particle sizer can detect volume sprays with particles in the range of 0.5 to 564 microns in three overlapping sub-ranges with the standard system. The Series 2600 instrument allows two scattering models to be selected. One is based on Fraunhofer diffraction which is better suited for liquid-droplet-spray (lds) and metal-in-liquid (mil), and the second is based on anomalous diffraction which can be utilized for particle-in-liquid (pil) and particle-in-air (pia).

The procedure to determine a grid pattern of the injector's particle size distribution was obtained by placing the injector in a supporting frame which can be moved along the x-, y- and z-direction in the vicinity of the particle sizer's laser beam. The Intelligent Controls IC5460 was used to control the injector pulse width and frequency while the sizer is acquiring data. Our experience so far is that an individual particle size measurement takes approximately two minutes.