Conf-9104185--2

DOE/MC/23174-94/C0320

Micronized-Coal-Water Slurry Sprays From a Diesel Engine Positive Displacment Fuel Injection System

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Contract Number:

DE-AC21-88MC23174

Conference Title:

1991 Spring Technical Meeting
Central States Section/Combustion Institute

Conference Location:

Nashville, Tennessee

Conference Dates:

April 21-24, 1991

Conference Sponsor:

The Combustion Institute

NOTE: one of 8 papers pulled from appendix of DOE/MC/23174-3490, to be announced separately as contractor conference papers

DISCLAIMER

MICRONIZED-COAL-WATER SLURRY SPRAYS FROM A DIESEL ENGINE POSITIVE DISPLACEMENT FUEL INJECTION SYSTEM

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Experiments have been conducted to characterize the sprays from a modified positive displacement fuel injection system for a diesel engine. Diesel fuel, water and three concentrations of micronized-coal-water slurry were used in these experiments. The injection system includes an injection jerk pump driven by an electric motor, a specially designed diaphragm to separate the abrasive coal slurry fuel from the pump, and a single-hole fuel nozzle. The sprays were injected into a pressurized chamber equipped with windows. High speed movies and still photographs of the sprays were obtained. In addition, instantaneous fuel line pressures and needle lifts were obtained. Data were acquired as a function of fluid, nozzle orifice diameter, rack setting and chamber conditions. The high speed movies were used to determine spray penetration and spray growth.

INTRODUCTION

To decrease the USA's dependence on petroleum, major efforts have been completed to develop diesel engines which can operate with coal [1-3]. A majority of these engines are large low to medium speed engines using micronized (SMD < 5 μm) coal-water-slurry (CWS) fuels. For example, a General Electric locomotive two-cylinder test engine has been operated successfully with coal-water slurry (CWS) fuels [4-6]. To assist the commercial development of such engines, the successful development of a CWS fuel injection system is needed. A successful commercial fuel injection system must (1) provide good fuel atomization with appropriate fuel penetration and (2) be tolerant of CWS fuels (i.e., possess repeatability and durability). To progress in both these areas, fundamental information is needed on the fuel injection process of CWS fuels.

This paper is a description of preliminary results from a project which will result in the characterization of CWS fuel sprays as a function of operating conditions and fuel specifications. The results of this study will assist CWS engine development by providing much needed insight about the fuel spray. In addition, the results will aid the development and use of CWS-fuel engine cycle simulations which require information on the fuel spray characteristics [7-9]. For successful cycle simulations, the evolution of the fuel spray geometry, droplet sizes, and droplet size distributions are needed as a function of time for a variety of operating conditions and fuel specifications.

BACKGROUND

In a diesel engine injector, the pressurized liquid fuel is the primary source of energy that produces the spray. Atomization is a result of jet instability due to the relative velocity of liquid and ambient gas. This type of injector is categorized as a single fluid pressure atomizer, in contrast to the air-assist atomizer where pressurized air is the primary source of energy for atomization. In pressure atomizers, atomization quality is controlled by fuel properties and injection pressure. For diesel engines, the fuel spray is injected into a confined combustion chamber that is under high pressure and high temperature conditions. Thus, the background air conditions are additional factors that affect the atomization quality of diesel engine injectors.

The first known study that included at least an attempt at characterizing a slurry spray was reported by Phatak and Gurney [10]. They obtained partial data on droplet size distributions from an experimental, air blast injector using coal-diesel (instead of coal-water) fuel slurries (20 or 40% coal by mass). Only limited data was reported, but they did show that for at least one operating condition, 80% of the fuel spray mass had droplet diameters of less than 20 μ for the air blast nozzle for one location and at one time. Nelson et al. [11] obtained both shadowgraphs and droplet size distribution data for CWS from engine injectors. The fuel injector was a modified 6 hole (0.35 mm dia) pencil nozzle (Stanadyne Roosa) with nozzle opening pressures of 800 and 2000 psig. For diesel fuel, 80% of the mass had droplet diameters less than 100 μ; whereas, for coal-water slurry, 80% of the mass had droplet diameters less than 400 μ. These results were for one location (1.25 inches from the nozzle tip) and for one time (0.5 ms after the spray tip passed). An air blast version of the nozzle showed improved (smaller droplets) performance. For both fuels, 80% of the mass had droplet diameters less than about 30μ.

Yu et al. [12] have reported the most complete study to date. They used a pneumatic, single-shot fuel delivery system and the injector was a pintle nozzle with injection pressures ranged from 10000 to 25000 psia (70 to 170 MPa). The fuel was injected into a constant volume chamber which contained pressurized room temperature gas with a density of 17.5 kg/m^3. Yu et al. [12] used a laser diffraction size analyzer with a 9 mm diameter laser beam. They examined two coal loadings (53 and 48% coal by mass) and three nozzle tip geometries, and reported their results as a function of injection velocity, fuel jet penetration distance, light transmission through the fuel spray, and mean droplet size. Average fuel injection velocity ranged from 220 to 450 m/s. They reported Sauter mean diameters (SMD) for the CWS of 25 and 54 μ for their limited tests.

EXPERIMENTAL FACILITY

Figure 1 shows the overall injection facility for this experiment which incorporates two fuel systems: one provides the diesel fuel used by the jerk-pump and the second provides the fuel, either diesel or slurry, which is injected by the nozzle. Figure 1 also shows the mechanical drive system which uses an electric motor to drive a cam. Attached to the drive shaft is a large (325 lbm) flywheel which minimizes variations in the rotational speed of the cam. The cam-follower mechanism translates the rotation of the cam into the reciprocating motion needed by the jerk-pump.

The high-pressure fuel system comprises: (1) the jerk-pump, (2) the diaphragm pump, (3) two check valves mounted on the diaphragm pump, and (4) the injector nozzle. The jerk-pump is a Bendix fuel pump which is used on many types of medium-speed diesel engines. The only modification to the pump is the addition of a fuel outlet passage which enables the low-pressure fuel system to circulate diesel fuel through the jerk-pump. A stainless-steel diaphragm has been inserted between the jerk-pump and the injector nozzle. This design is similar to that used by Leonard and Fiske [13]. The system operates in the same way as the conventional system except that in the modified system the diesel fuel which is forced out of the pump is used to increase the pressure on one side of the diaphragm pump. The pressure is transferred through the diaphragm to the CWS side of the pump--this forces CWS down the fuel line and into the injection nozzle. The purpose of the diaphragm is to isolate the jerk-pump from the abrasive coal particles by using diesel fuel on the jerk-pump side and coal-water slurry on the nozzle side. The nozzle used is a Bendix injector which is used on medium-speed diesel engines. Modifications to the nozzle have been limited to the installation of a needle lift transducer, increasing clearances in the needle valve assembly, and the use of custom nozzle tips. The custom nozzle tips allow the use of various nozzle tip geometries with various numbers and sizes of orifices. The fuel pressure is measured by the use of a strain gauge pressure transducer.

The final aspect of the injection facility is the pressurized chamber. In one direction the fuel spray was directed while in the perpendicular direction visualization of the spray was possible through high pressure windows. The spray was back-lighted through one window and photographed through the other. High-speed (11,000 frames/sec), 16 mm movies of the spray and high-resolution still photography using a high intensity microflash were obtained.

EXPERIMENTAL PROCEDURES

The basic slurry fuel was a commercially available coal-water slurry obtained from Otisca Industries. The details of this slurry have been reported elsewhere [4-6]. In summary, the base CWS contained 50% coal, 49% water and 1% lignosulphonate (a stabilizer). The coal was a high-volatile subbituminous which was cleaned to less than 0.8% ash (on a dry coal basis) with a Sauter-mean particle diameter of 3.0 μ.

The experimental procedure included the following steps. First, the cam shaft was accelerated to a steady state speed of 550 rpm. The rack was pulled to a predetermined position and injection would begin. The movie camera was started and an electronic trigger was sent to the data acquisition system when the speed of the film was greater than 900 frames per second.

RESULTS AND DISCUSSION

To obtain instantaneous mass flow rates, average coefficients of discharge (C_D) were determined. This was completed by the use of the instantaneous needle lift, fuel line pressure, total average mass of fuel injected and a simple incompressible flow model. From this calculation, the average coefficient of discharge was 0.516.

Figure 2 shows four sequential frames from a portion of a movie of one injection. The time between frames is about 0.1 msec. From these movie frames, spray propagation and development were determined. As shown, the propagation of the fuel jet is rapid at the start. As the penetration of the fuel increases, the development of a head vortex is noted. The size of the head vortex increases due to additional fuel from the injector on one side (upstream) and due to entrained gas on the other sides. The total spray divergence angle is about 20° for this case.

Figure 3 shows the instantaneous fuel line pressure and needle lift as a function of time. As shown, fuel pressure increases and when the pressure is about 26 MPa (3900 psia) the needle lifts. The pressure decreases slightly due to the start of injection and then continues to increase. The maximum pressure is 55 MPa (8200 psia) which occurs 4.0 msec after the start of injection. From a model of this injection process, nozzle exit velocities were calculated and were typically between 100 and 200 m/s.

CONCLUSIONS

1. Micronized coal water slurry was injected successfully using a modified diesel engine positive displacement injection fuel injection system.

2. Injection pressures as high as 55 MPa (8200 psia) were measured.

3. Back-lighted, high-speed (11,000 frames/sec) movies of the injection process were obtained.

ACKNOWLEDGEMENTS

This work was supported by a sub-contract from General Electric-Transportation Systems Business Office as part of a contract with the U.S. Department of Energy-Morgantown Energy Technology Center. The contents of this paper do not necessarily reflect the views of General Electric or the Department of Energy.

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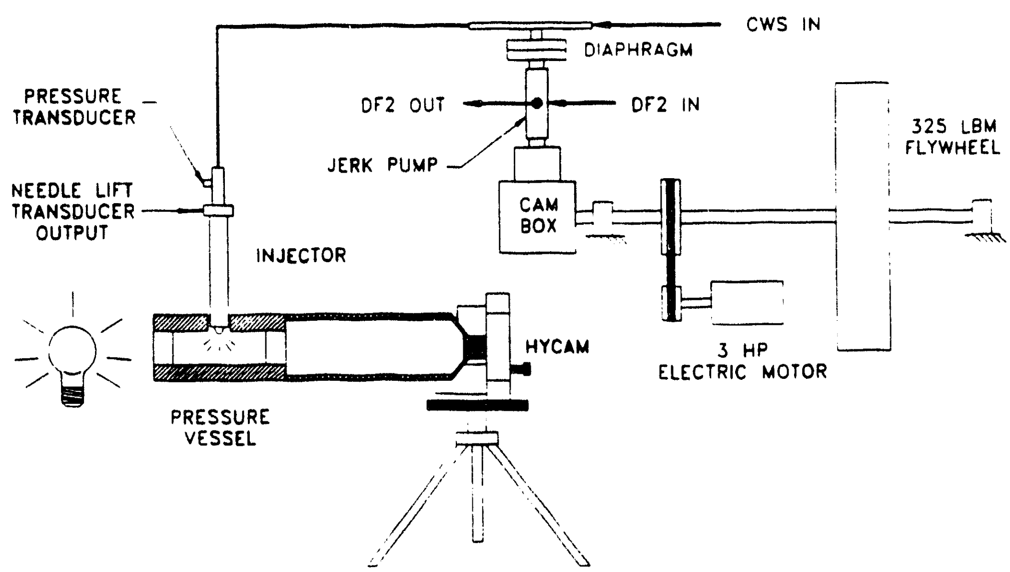

Figure 1. Schematic of the experimental facility.

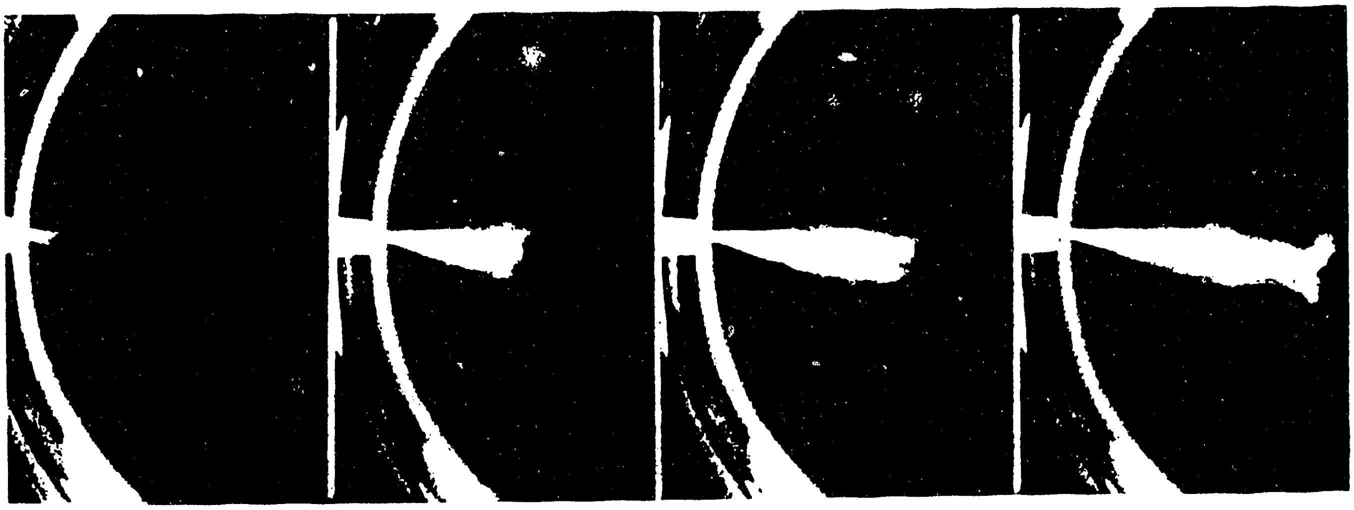

Figure 2. Sequential movie frames of the injection process.

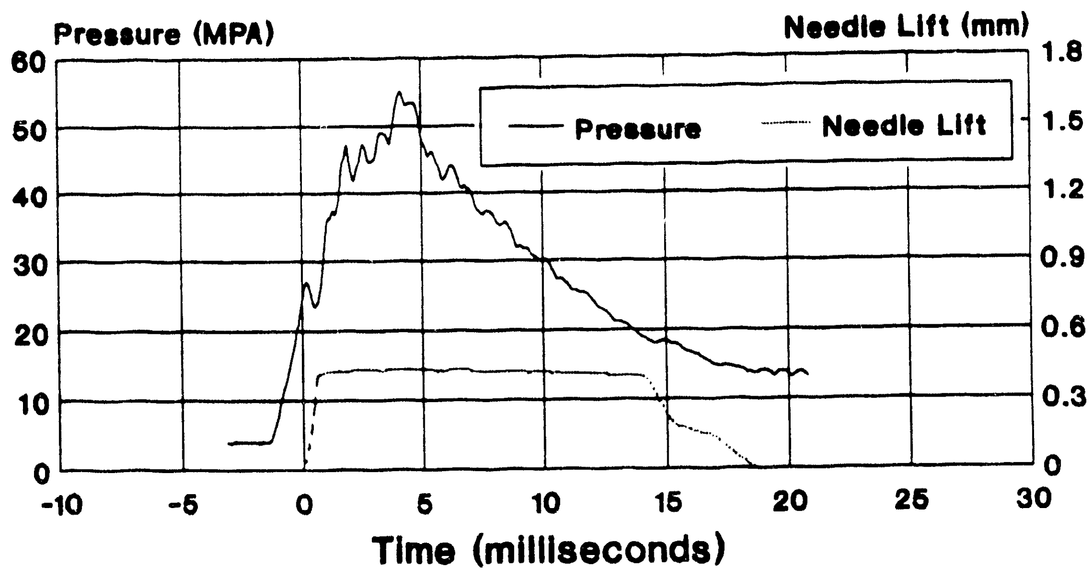

Figure 3. Instantaneous fuel line pressure and needle lift as a function of time.

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