Photographic Study on Air-Assisted Fuel Spray in an Optically-Accessible Cylinder of a Test Rig

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ABSTRACT

In this study, the experiment of air-assisted fuel injection system was performed in a test rig of optically accessible two-stroke cycle engine. The nozzle was mounted in the cylinder head and the fuel spray was directed toward the top of piston. The NAC E-10 high speed camera was used in purpose of recording the qualitative flow visualization. The Malvern 2600 series laser diffraction particle sizer was used for measurement of the quantitative fuel droplet.

From the series of tests, the results were obtained: the scavenging air flow influences the whole fuel spray significantly and makes it toward the exhaust port at wide port opening. It also illustrates that the vortexes appear symmetrically relative to the center line of nozzle at the conditions of low scavenging air flow rate. The most fuel spray of air-assisted fuel injection system is near the bottom of the cylinder. For improving this phenomenon, remounting the nozzle with a leaning angle of 30 ^{0} could make some of the fuel spray stay in the top of cylinder.

INTRODUCTION

The use of air-assisted fuel injection system on two-stroke cycle engine has gained worldwide attention. It is regarded as a promising measure for two-stroke cycle engines to prevent the short-circuiting of fuel during the scavenging process. There have been minimal experimental studies (1)(2)(3) concerning the relationship of the impingement of fuel spray and the mixture formation in the combustion chamber. Sato and Nakayama (1) found that many problems would occur when the nozzle was mounted in the cylinder head and the fuel spray was directed toward the top of piston. The effect of spray impingement on the piston wall is helpful for the diffusion of fuel in the combustion chamber for some cases, e.g., OSKA system (2)(3). Giovanetti (4) et al. applied the high pressure direct injection system to the spark ignition engine with different mounting angle of injector and different shapes of combustion chamber for the improvement of HC emission. Few studies (5)(6) on the performance of air-assist atomizers have been reported in the literature. A new air assisted fuel injection system has developed by the authors (7)(8) in response to the demand for fuel economy and emission improvements.

Therefore, in this study, the fuel spray characteristics of the air-assisted fuel injection system was investigated systematically. A high speed camera was employed for the photography of the spray characteristics. At the same time, the laser diffraction particle sizer was also used for the measurement of the particle size of the fuel spray.

EXPERIMENTAL APPARATUSES AND MEASUREMENT TECHNIQUES

Fig. 1 shows a schematic diagram of the experimental system. As illustrated in Fig. 2, upper part of the test rig was inserted with a transparent glass, and the position of the piston could be adjusted by a screw rod. The cross sectional area of the transparent glass was 74 × 74 mm square with the thickness of 2 mm. The part of the cylinder below the ports (including the ports) was remained unchanged. The air-assisted fuel injection system was composed of four subsystems: fuel supply, air supply, injector unit and electronic control unit. The fuel supply system includes an electric fuel pump with a pressure regulator. The air supply system includes an air compressor and pressure regulator. The injector unit includes a fuel injector, an air injector, adapter and a nozzle with a poppet type valve. The flow rate and timing of the fuel injected out of the nozzle were determined by the air injection pressure and air injection timing and not to be influenced by the fuel injection pressure. The fuel spray was recorded by the NAC E-10 high speed camera with the speed of 2000 frames per second. The area of the intake port and the exhaust port were adjusted as 1258.1 mm^2 and 773 mm^2 respectively at wide port opening (BDC), the area of the intake port and the exhaust port were 198 mm^2 and 432.5 mm^2 respectively at narrow port opening. Three intake air temperatures were used; i.e. the room temperature (about 33 °C) , 60 °C and 90 °C. In order to match a two-stroke cycle engine during low load operation; two cases for scavenging air flow rate of 75 and 150 l/min were tested. The air injection pressure can influence not only S.M.D. but also penetration and the velocity of fuel spray. In this study, the air injection pressure varied from 100 to 500 kPa were tested. Table 1 shows the injection conditions, Fig. 3 indicates the injection rate corresponding to the conditions listed in Table 1. The average amount of fuel spray was 0.008 g for every revolution, and the regular gasoline was used as the test fuel .

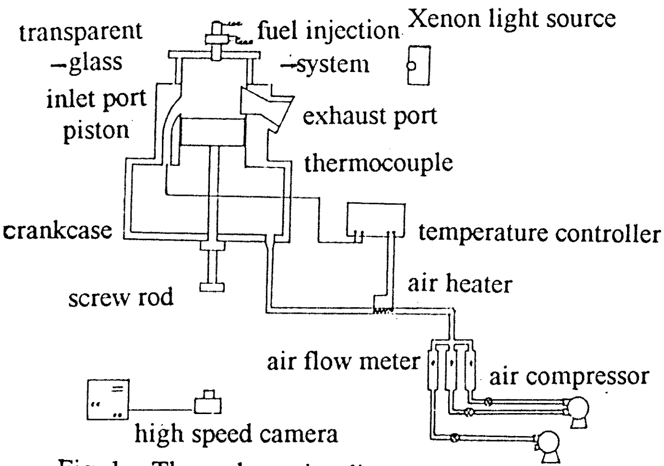

Fig. 1 The schematic diagram of the experimental system

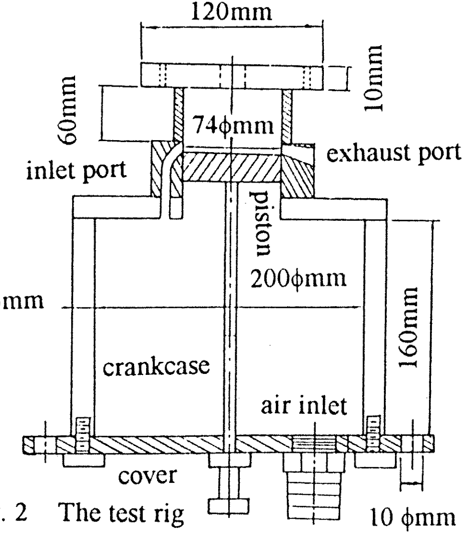

Fig. 2 The test rig

Table 1 Injection conditions

Air injection timing (AIT)	150 deg-ATDC
Time duration of air injection (AID)	2.0 ms
Fuel injection timing (FIT)	120 deg-ATDC
Time duration of fuel injection(FID)	2.0 ms

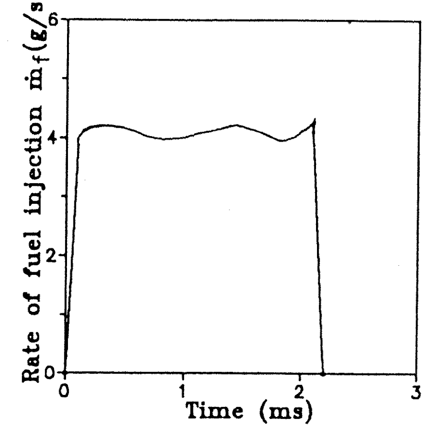

Fig. 3 Rate of fuel injection at condition shown in Table 1

Fig. 4 shows the whole experimental set-up of the laser diffraction particle sizer. This instrument consists of a transmitter, receiver, signal processing units, and a mini-computer. Measurements were made using the calibrated Malvern instrument at various axial and radial locations in the spray for different air injection pressure. Variation of S.M.D. and size distribution are presented and discussed.

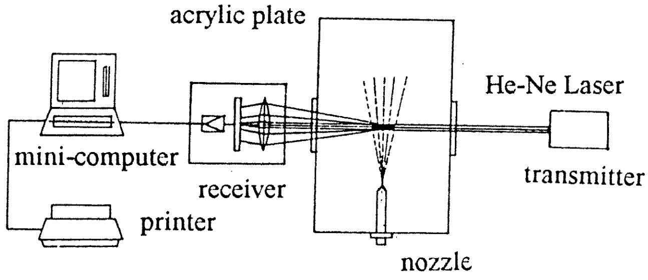

Fig. 4 The experimental set-up of the laser diffraction particle sizer

EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 5 shows a series of instantaneous photographs of fuel spray with no scavenging air flow. The spitting and streaking of liquid fuels are commonly observed in atomization when viewed with a high speed camera. This phenomena are related to eddies around the break region in the fuel flow symmetrically to the center line of the nozzle. In this study, the fuel spray is directed toward the top of piston, and the most fuel spray of air-assisted fuel injection is appeared near the bottom of the cylinder. This phenomenon is pretty bad for the initiation of the combustion process by the spark plug. For improving this phenomenon, remounting the nozzle with a leaning angle of 30 ° could make part of the fuel spray stay around the spark plug. Obviously, Fig. 5(C) shows that part of the fuel spray stay in the top of cylinder in the later stage of injection. In order to reduce the probability of misfire, it is reasonable to remount the nozzle with a leaning angle for this fuel injection system.

Fig. 6 shows a series of instantaneous photographs of fuel spray with scavenging air flow. The fuel spray is moved toward the exhaust port by the scavenging air flow at the conditions of high scavenging air flow rate and wide port opening. In addition, the scavenging air flow influences the fuel spray distribution above the inlet port more obviously in the case of narrow port opening, but it seems to be not influenced by the scavenging air flow at the other part of the transparent cylinder. In other words, the scavenging air flow moves toward the top of the transparent cylinder with higher speed at narrow port opening, and its radial velocity is too small to influence the fuel spray in other part of the transparent cylinder. On the other hand, the scavenging air flow influences the whole fuel spray apparently at wide port opening. That is, the scavenging air flow moves through wide, spread of the transparent cylinder with lower speed at wide port opening. Above all, the short-circuiting of fuel spray may appear more possibly at the conditions of high scavenging air flow rate and wide port opening, even though the in-cylinder fuel injection is used.

The characteristics of fuel spray are influenced apparently by the fuel injection pressure for the liquid fuel injection system, such as S.M.D., penetration and the velocity of fuel spray. The high air injection pressure can improve the spread of fuel, the velocity of fuel spray and penetration. From the above high speed photographs, the fuel clean time duration[*] and the velocity of fuel spray can be measured. Fig. 7 shows that the axial velocity may approach a stable value at a certain downstream distance for any air injection pressure, such as 17 mm downstream along the centerline for 200 kPa , 25.5 mm for 300 kPa, 28.5 mm for 400 kPa and 29 mm for 500 kPa. Obviously, the last three types are similar to each other. The fuel clean time duration of the system is equal to 2 ms (AID, or the operation timing of the check valve), and is independent of the air injection pressure. All of the above results can help us choose the suitable air injection pressure for this injection system.

In this study, the drop size distribution of the air-assisted fuel injection system was measured quantitative in the atmosphere in order to understand the effect of air injection pressure on atomization. The interaction among the drops, the surrounding air and the variation of mean drop size in the sprays are reported here. Fig. 8 shows that the variation of S.M.D. at 10 mm downstream along the centerline from the nozzle exit is greatly. The maximum value of the mean drop size approaches to 43 μm, and the structure of the fuel spray is not a complete hollow cone. That is , the fuel spray will diffuse to the centerline immediately after injection. The size distribution is uniform after 20 mm downstream along the centerline from the nozzle exit. Certainly, the mean drop size is larger on the outer edge of the fuel spray, especially when the penetration length is smaller than 10 mm downstream along the centerline from the nozzle exit. Basically, the fuel spray of the air-assisted fuel injection system is quite uniform, and the fuel spray is not only concentrated on the outer edge of the hollow cone. Fig. 9 and Fig. 10 are derived from Fig. 8 which show that S.M.D. approaches a stable value of about 15 μm at 30 mm downstream along the centerline from the nozzle, and the mean drop size near the nozzle tip and the outside of the hollow cone are larger than other positions of the fuel spray. In other words, S.M.D. increases with radial distance from the axis and decreases with distance downstream along the center line. Fig. 11 shows the higher the fuel injection pressure causes the smaller the S.M.D. But the decreasing rate in S.M.D. is not greatly influenced by the air injection pressure for this fuel injection system. Comparing the results of Fig. 7 and Fig. 11, it is reasonable to choose 300 or 400 kPa as the air injection pressure of the air-assisted fuel injection system.

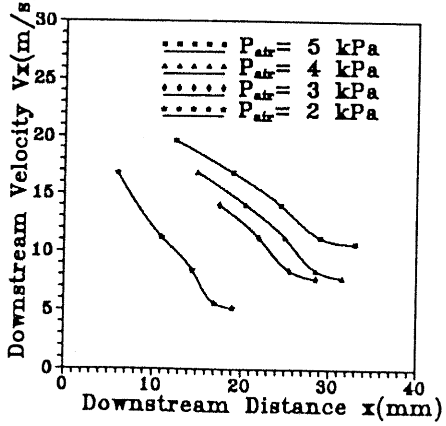

Fig. 7 Axial velocity as function of downstream distance at several air injection pressures from high speed photographs

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[*] fuel clean time duration-the time duration for the fuel to be pushed out of the nozzle tip completely.

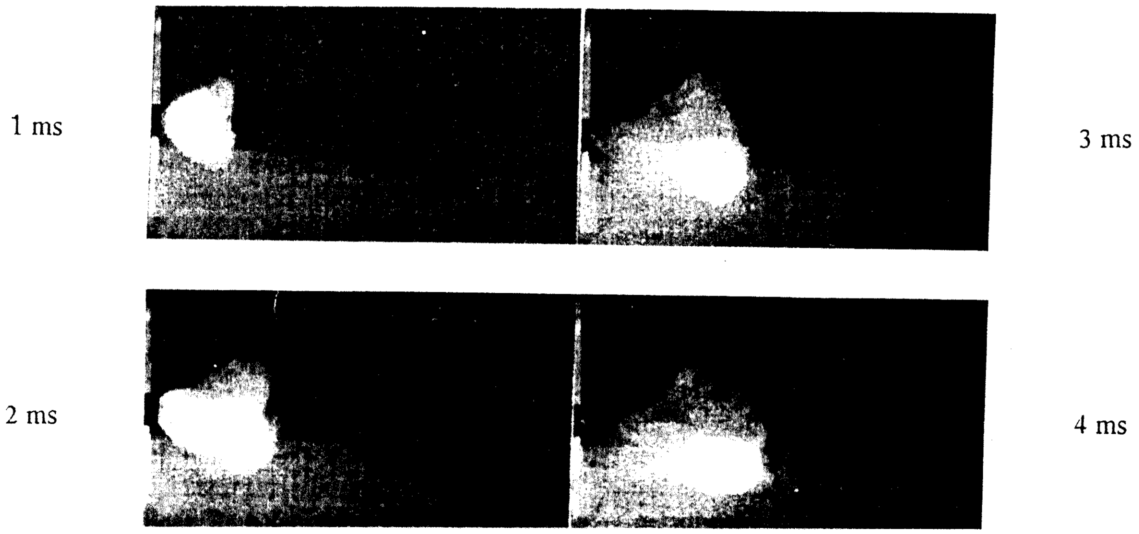

Fig. 5(A) The axial photography of fuel spray in the atmosphere , , No scavenging air flow, P_{air}= 500 kPa, P_{oil}=200 kPa

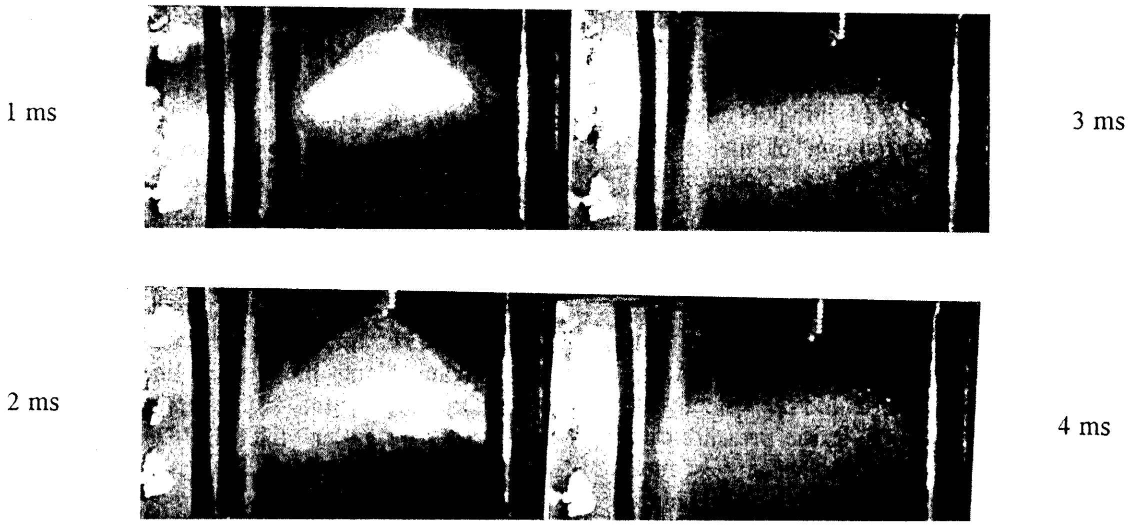

Fig. 5(B) The room temperature 33 °C, the center line of the nozzle is vertical to the piston head, No scavenging air flow, P_{air}= 500 kPa, P_{oil}= 200 kPa

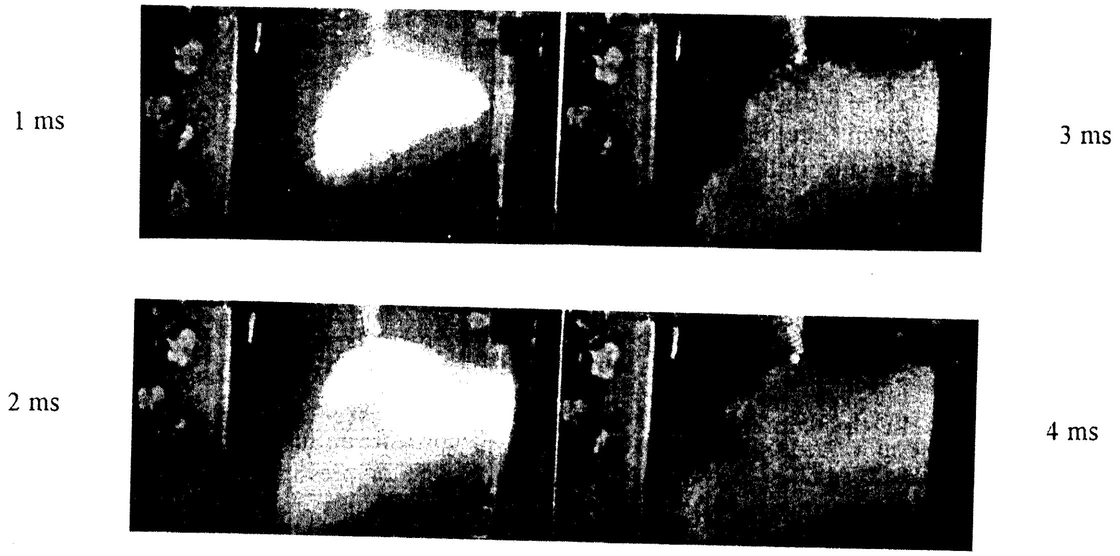

Fig. 5(C) The room temperature 33 °C, remounting the nozzle with a leaning angle of 30 °, No scavenging air flow, P_{air}= 500 kPa, P_{oil}= 200 kPa

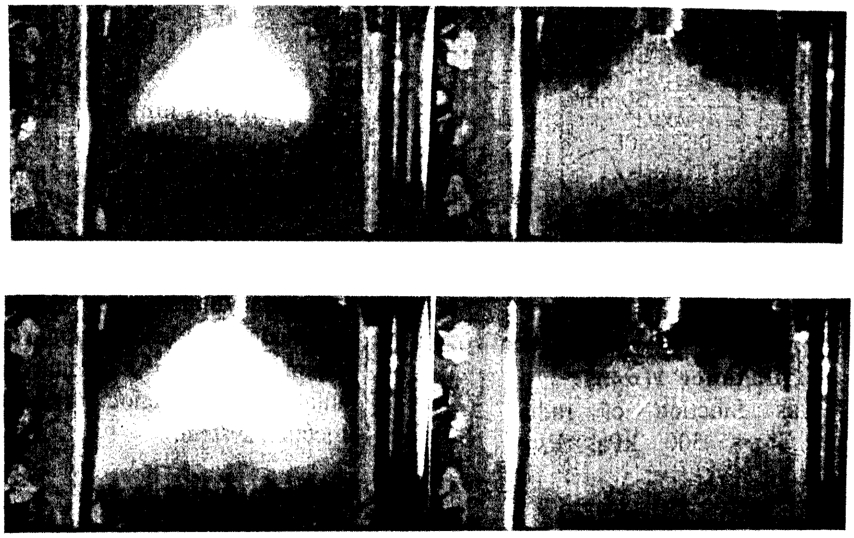

Fig. 6(A) Narrow port opening, the scavenging air flow rate 75 l/min, the room temperature 33°C, P_{air}= 500 kPa, P_{oil}= 200 kPa

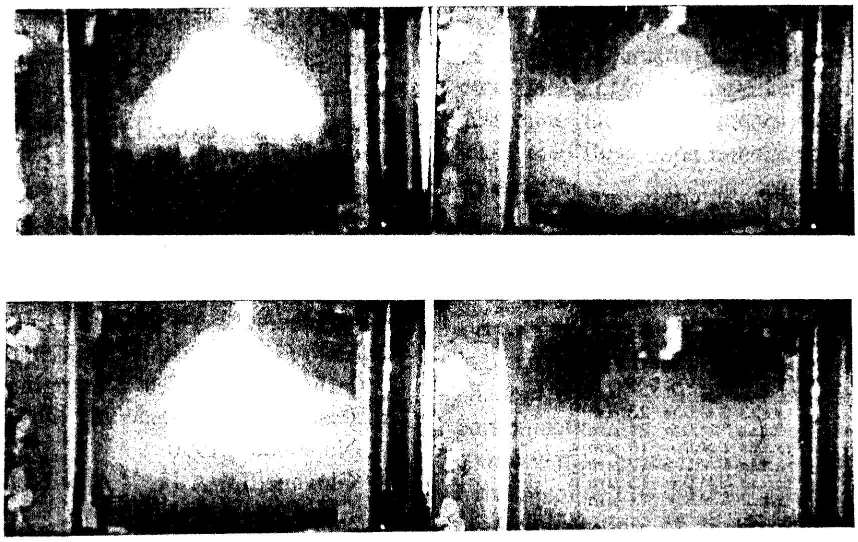

Fig. 6(B) Wide port opening, the scavenging air flow rate 75 l/min, the intake air temperature 60 °C, P_{air}= 500 kPa, P_{oil}= 200 kPa

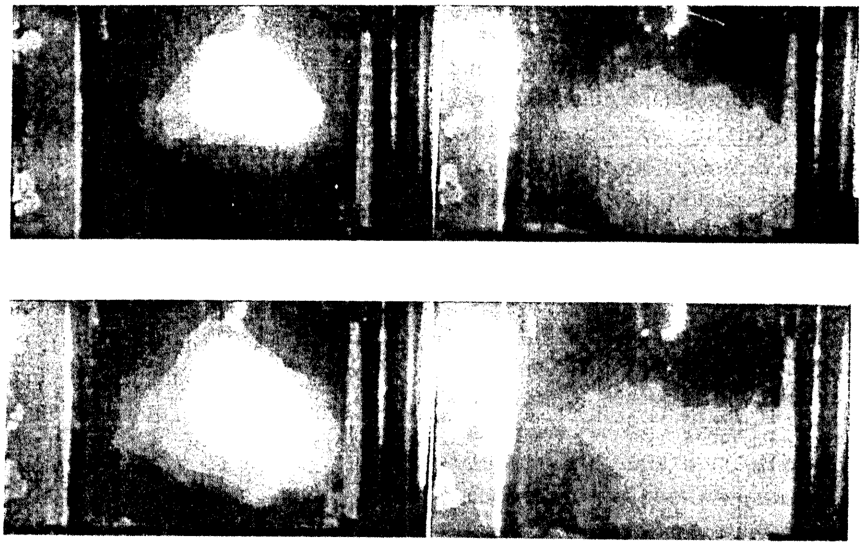

Fig. 6(C) Wide port opening, the scavenging air flow rate 150 l/min, the intake air temperature 90°C, P_{air}= 500 kPa, P_{oil}= 200 kPa

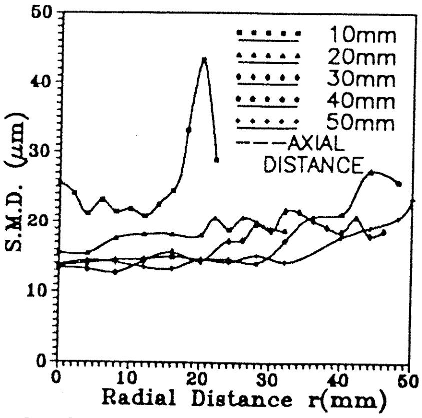

Fig. 8 S.M.D. as function of radial distance, P_{air}= 500 kPa, P_{oil}= 200kPa

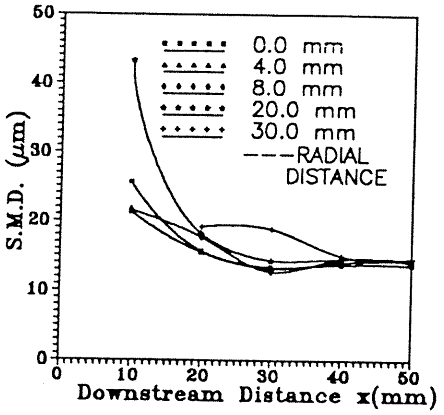

Fig. 9 S.M.D. as function of downstream distance, P_{air}= 500 kPa, P_{oil}= 200 kPa

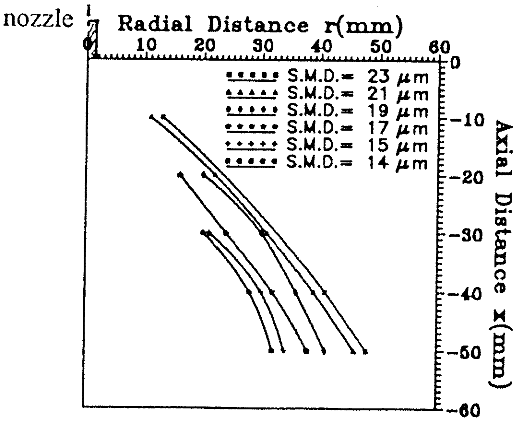

Fig. 10 Isolines of S.M.D., P_{air}= 500 kPa, P_{oil}= 200 kPa

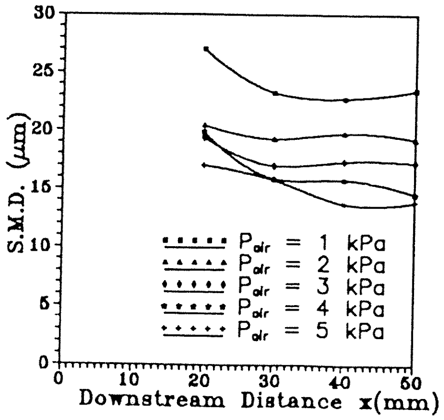

Fig. 11 S.M.D. as function of downstream distance at several air injection pressure

CONCLUSIONS

1. The short-circuiting of fuel spray may appear more possibly at the conditions of high scavenging air flow rate and wide port opening, even though the in-cylinder fuel injection is used.
2. The fuel spray could remain in the top zone of cylinder when the nozzle was mounted with a leaning angle of 30 °, and 300 or 400 kPa was recommended as the suitable air injection pressure for this injection system.

ACKNOWLEDGMENTS

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