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Numerical Investigation of the Effects of a Skimmer on the Structure of Dense Sprays

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Abstract

A skimmer is sometimes used as a semi-intrusive experimental technique in optical diagnostics of dense sprays to reduce the signal attenuation due to multiple scattering from drops. Its effects on the spray structure and drop size distribution should be understood and quantified in order to make judicious use of this technique. The effects of skimmer on the structure and drop size distribution in a dense diesel spray were studied numerically using the KIVA3 code.

Introduction

Understanding of the breakup mechanism for diesel sprays is of importance for development of atomization models and to improve the design of diesel engines in terms of performance and pollutant emissions. The quality of the spray is in general assessed by the drop size distribution, breakup length, and penetration. However, the near-nozzle spray is almost exclusively dense which limits the application of optical diagnostics due to intensive signal attenuation as a consequence of multiple scattering from drops. A properly designed skimmer can be used to minimize the effects of multiple scattering and therefore renders the optical diagnostics of dense spray feasible [1,2]. Two factors must be considered in the design of a skimmer for dense spray study: (1) the spacing of the skimmer should be narrow enough to minimize signal attenuation by multiple scattering, and (2) use of the skimmer should not cause significant disturbances to the measured portion of the spray. Obviously these are two competing factors and there exists an optimal spacing of the skimmer for a given spray. Due to the intrusive nature of such a technique, the potential disturbances of a skimmer to the spray have long been debated. This debate is very difficult, if not impossible, to be resolved experimentally. It is possible, however, to provide the answer numerically by comparing the modelled results obtained using a skimmer with those without the skimmer.

In the present study, the KIVA3 code [3] was used to investigate the effects of the use of a skimmer on the structure and drop size distribution of a dense diesel spray formed from a simple pressure atomizer. Three spacings of the skimmer were considered in the present numerical investigation.

Numerical Method and Computational Conditions

The KIVA3 code solves the unsteady three-dimensional compressible Navier-Stokes equations coupled with chemical reactions and spray dynamics using the control volume method. Details of the numerical method and physical models employed in the code are discussed in [3,4]. In the present calculations, the gas phase turbulence was modelled using the k-ε model and the effect of turbulence on drop dynamics was taken into account. The TAB model was employed to simulate the secondary breakup processes of the diesel spray. The model assumes that the size of drop parcels at the injector is the same as the injector diameter.

Numerical calculations were performed in a three-dimensional domain of 3.0cm (x, width) × 3.0cm(y, depth) × 10.2cm(z, height). The front view of the computational domain is shown in Fig.1. The domain was divided into 9 blocks in order to resolve the details of the skimmer. A grid of 21(x)×19(y)×53(z) was used in all the calculations. This 9-block geometry setup was maintained for calculation of the no skimmer case by replacing the solid boundaries in blocks 2, 3, 5, 8, and 9 with fluid interfaces. The injector diameter was assumed to be 0.34 mm. The injector was located at (0,0,9.8cm) and the diesel fuel was injected downward. The injection pattern was a half-sine one with a duration of 3 ms and the amount of fuel injected 34 mg. The injection velocity was constant at 100 m/s. The number of drop parcels in all the calculations was 50,000. The sharp tip of the skimmers was located at 10

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mm below the injector. Three skimmer spacings, 0.5, 1.0, and 2.0 mm were calculated to investigate its effects on the spray. It is worth pointing out that the collision sub-model of KIVA3 was turned off in the present calculations. Numerical experiments indicated that an erroneous spray pattern was produced in the presence of the skimmer if the collision sub-model was turned on.

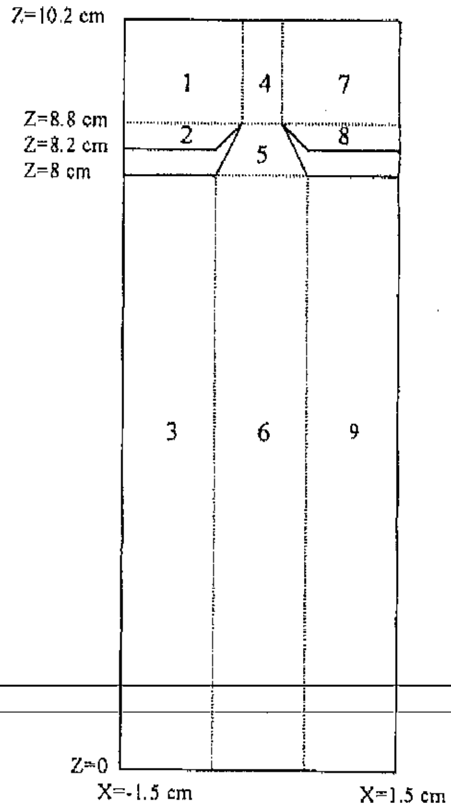

Fig.1 Schematic front view of the computational domain.

Results and Discussions

In this study, the spray patterns predicted with and without the skimmer at 1 ms after the injection were analyzed. Figs. 2 and 3 show the front view of the spray (drop location and relative drop size) for the cases of no skimmer and with a 0.5 mm spacing skimmer, respectively. Comparison of these figures shows that the effects of this 0.5 mm spacing skimmer are not only to produce a much narrower spray by skimming significant portion of the drops from the spray but also to cause a reduced spray penetration. The reduced penetration shown in Fig.3 can be explained by the the shift to smaller drop sizes (the drop size distribution will be shown later).

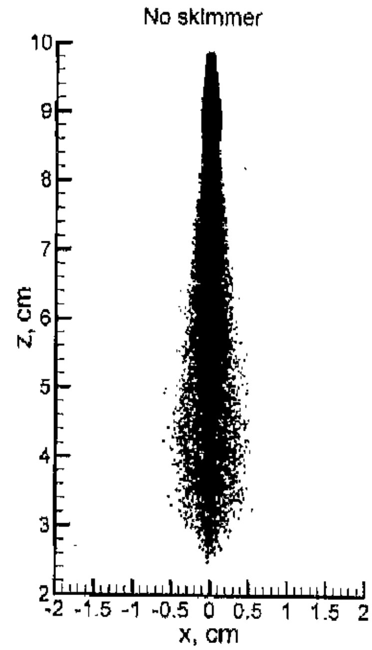

Fig.2 Front view of the spray in the case of no skimmer.

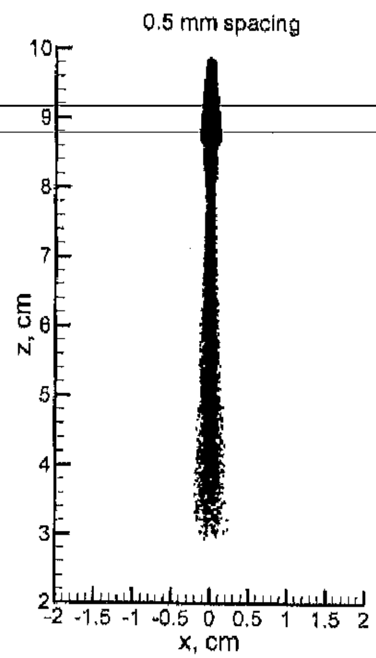

Fig.3 Front view of the spray in the case of inserting a 0.5 mm spacing skimmer.

In experimental investigation of a dense spray using an optical diagnostic method with the help of a properly designed skimmer, a laser sheet is often used to illuminate the spray core [1,2]. It is believed that the skimmer will not greatly affect the spray on the laser sheet plane. To numerically simulate the laser sheet used in the experiment of Gülder et al. [1], drops in the predicted spray were filtered to remove those whose location were outside the thickness of the laser sheet defined as [-0.15 mm, 0.15 mm]. Side views of the filtered spray (only drops inside the laser sheet) are shown in Figs.4, 5, 6, and 7 for cases without the skimmer and with the skimmer, in order of decreasing skimmer spacing. These figures display the drop location and relative drop size. Overall the spray patterns shown in these four figures are very similar, indicating that the presence of the skimmer does not significantly affect the spray in the plane of the 'laser sheet'. A careful examination of the spray tips shown in these figures reveals that the 2mm spacing skimmer has no effect on the penetration of the spray. Use of the 1mm spacing skimmer slightly reduced the spray penetration, Fig.6. The spray penetration in the case of using the 0.5 mm spacing skimmer, Fig.7, was significantly reduced, which has already been seen from the front view of this case shown in Fig.3. Examination of relative drop sizes displayed in these four figures show that there is a trend of decreasing drop size as the skimmer spacing decreasing. This trend is consistent with the decreased spray penetration with decreasing the skimmer spacing.

~~The trend of decreased drop size with decreasing the skimmer spacing can be explained by the increased~~ shear between the central portion of the spray (in the 'laser sheet') and the surrounding air as the skimmer spacing decreases. The skimmer can be viewed as a slot nozzle in the present study.

The predicted drop size distributions for the four cases (without skimmer, and three skimmer spacings) at a location of 50 mm (±2.5mm) below the injector and in the plane of the 'laser sheet' are shown in Fig.8. Curves shown in Fig.8 were results of polynomial fitting to the scattered data points due to insufficient number of data points. These curves indicate that the mean drop size decreases as the skimmer spacing decreases. In addition, use of the 2mm spacing skimmer has almost no effect on the drop size distribution at the location considered. The drop size distributions shown in Fig.8 provides an explanation to the variation of spray penetration observed in Figs.4, 5, 6, and 7.

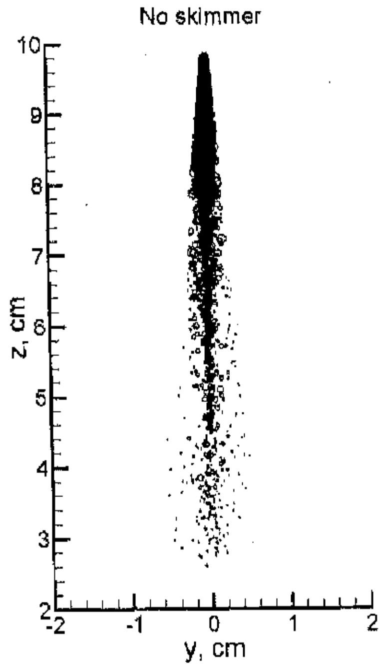

Fig.4 Side view of the spray in the laser sheet plane in the case of no skimmer.

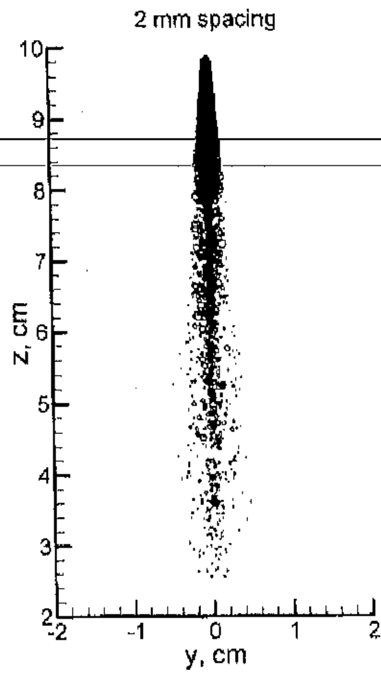

Fig.5 Side view of the spray in the laser sheet plane for the case of using the 2mm spacing skimmer.

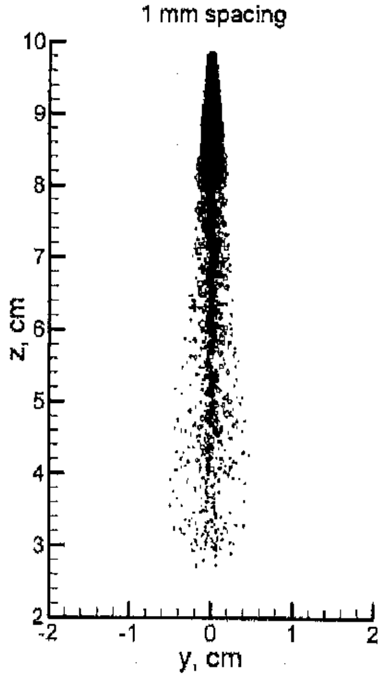

Fig.6 Side view of the spray in the laser sheet plane for the case of using the 1mm spacing skimmer.

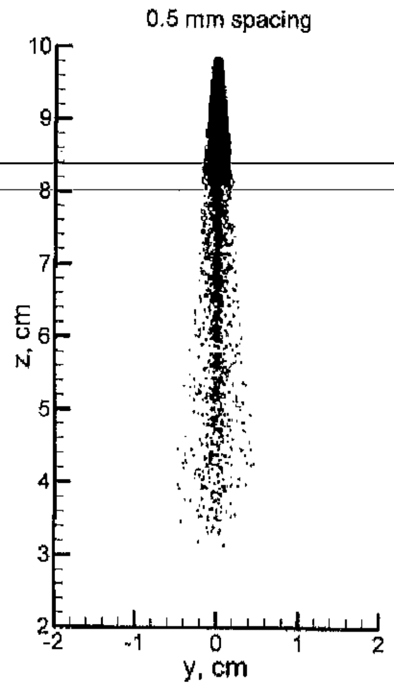

Fig.6 Side view of the spray in the laser sheet plane for the case of using the 1mm spacing skimmer.

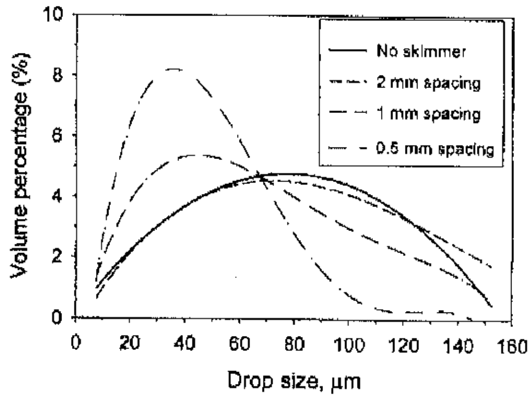

Fig.8 Drop size distributions at a location of 50 mm below the injector and in the laser sheet plane for the four cases studied.

Conclusions

The effects of a skimmer on the structure of a dense diesel spray were numerical investigated using the KIVA3 code. Numerical results show that the skimmer has negligible effect on the central portion of the spray if the skimmer spacing is sufficiently wide. The effects of the skimmer on the spray increase as the skimmer spacing reduces. The smaller the skimmer spacing, the finer the drops in the central portion of the spray and the shorter the spray penetration.

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