

High Speed Imaging Study on the Spray Characteristics of Dieseline at Elevated Temperatures and Back Pressures

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ABSTRACT

Dieseline combustion as a concept combines the advantages of gasoline and diesel by offline or online blending the two fuels. Dieseline has become an attractive new compression ignition combustion concept in recent years and furthermore an approach to a full-boiling-range fuel. High speed imaging with near-parallel backlit light was used to investigate the spray characteristics of dieseline and pure fuels with a common rail diesel injection system in a constant volume vessel. The results were acquired at different blend ratios, and at different temperatures and back pressures at an injection pressure of 100MPa. The penetrations and the evaporation states were compared with those of gasoline and diesel. The spray profile was analyzed in both area and shape with statistical methods. The effect of gasoline percentage on the evaporation in the fuel spray was evaluated. The blend ratio shows large impacts particularly in liquid phase area, on the liquid core length and the gas-to-liquid ratio (by area) at higher temperatures. It was found that the liquid phase areas and liquid core lengths produce a profile with relatively stable values in the late stage at 700 K and 820 K. A higher temperature or a higher gasoline percentage can advance the turning point time to the stable value. The atmospheric gas density mainly affects the penetration and propagation speed and has a minor impact on the gas-to-liquid ratio.

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INTRODUCTION

The automotive industry has to face both the challenges of pollutant emissions control and necessary fuel economy improvements as the regulation for vehicle engines have become ever stricter with CO₂ emissions in particular starting to become restricted. Many technologies have tried to combine the advantages of compression ignition (CI) and spark ignition (SI) engines [1] and concepts such as HCCI, HCII, PCCI, PPCI/Dieseline, and RCCI [2, 3, 4, 5, 6, 7] have been studied widely. Offline blended diesel and gasoline (dieseline) is thought to be one of the most practical and straightforward solutions in recent decades [8, 9]. Furthermore, the full-boiling-range fuel has been proposed as a direction of future internal

combustion engine fuel since the wide-distillation fuel has presented advantages in compression ignition [10]. The blended fuel of gasoline and diesel can be a representative of the full-boiling-range fuel, which makes dieseline study even more attractive.

The spray characteristics are the key factor in CI combustion because the mixture formation directly determines the combustion process and soot formation [11, 6, 12, 13]. Previous studies have investigated the spray characteristics of gasoline and diesel [14, 15, 16, 17] under high injection pressure with high back pressures, however little on the dieseline spray under high temperatures and pressures has been studied

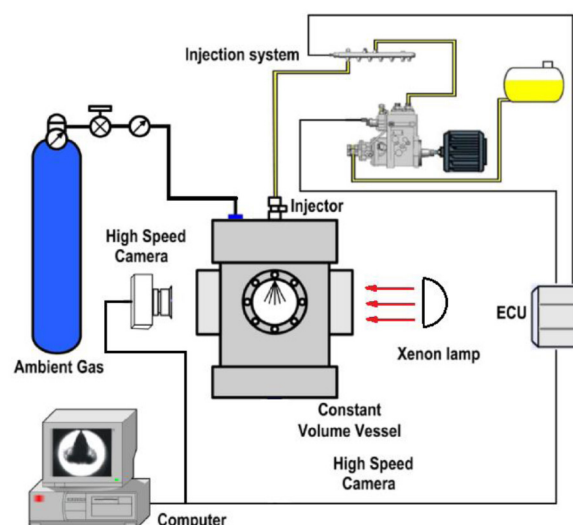
The normal side or backlight luminance high speed imaging can only reveal the liquid phase. Thus the traditional methods for investigating spray characteristics are high speed Schlieren or shadowgraph [14, 18, 19, 20, 21]. But Schlieren and shadowgraph may be too sensitive to the density gradient of the background gas near the high temperature heater particularly at high pressure, which brings difficulties into the program analysis[14]. Furthermore, identifying the liquid phase is normally threshold-dependent and sometimes it is difficult to distinguish the boundary of the dense liquid area in Schlieren/shadowgraph pictures.

The authors used a near-parallel backlight and a small lens aperture to realize a high speed imaging test which can observe the gaseous phase in the spray and is not so sensitive to the high temperature and high pressure background gas. The spray characteristics of pure gasoline, pure diesel and two blend fuels were studied in a constant volume vessel under high temperatures (up to 820 K) and high back pressures (up to 4 MPa). The quantitative comparisons of gaseous/liquid phase area, penetration and liquid core length were conducted and the effects of blend ratio, temperature and back pressure were discussed.

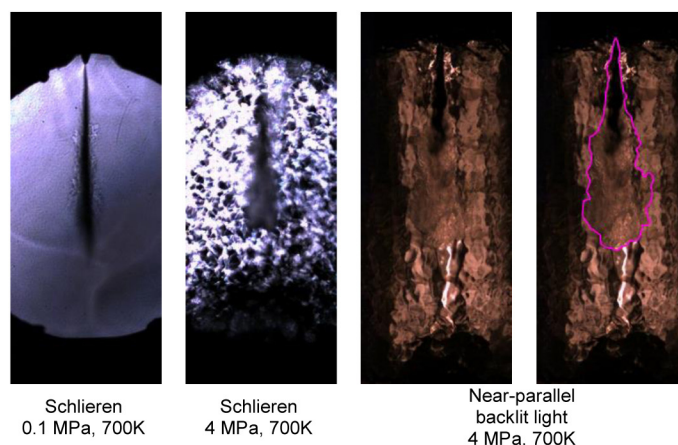
Experimental Setup

The experiment was conducted in a high pressure high temperature constant volume vessel. The system is shown in Figure 1a. The single-hole diesel injector was mounted at the top of the chamber and two heating cartridges (2.6 kW in total) were installed at the bottom, which were separated in the testing region by a metal plate to prevent direct contact with the fuel. Optical access is provided via four quartz windows at each side, 100mm in diameter and 70mm thick. The maximum temperature that can be achieved is about 930K and the designed maximum pressure is 6 MPa. A temperature uniformity of $\pm 3\%$ can be achieved within a cylinder-shaped central region of the vessel after the vessel pressure reaches the target value, which is up to the state when the in-cylinder fuel injection starts. In this study, the spray only propagates in the center region and the repetition of the temperature distribution in the center area is confirmed by previous study [22]. In this experiment the highest test temperature and pressure is 820K and 4 MPa. In order to avoid auto-ignition, the vessel is pressurized by nitrogen. The other details of the injection system are shown in Table 1.

The fuels used in the experiment include 95# gasoline (G100), 0# diesel (G0), and 50% gasoline (in volume) in diesel (G50) and 80% gasoline in diesel (G80).



(a)



(b)

Figure 1. System and method; (a) experimental setup; (b) a comparison of Schlieren and near-parallel light illumination.

Table 1. Fuel Supply System.

Injector Type	Solenoid
Injection Pressure	100 MPa
Injector hole diameter	0.168 mm
Injection Duration	1.5 ms

The images were captured using a Phantom V7.3 high speed CMOS camera at a speed of 20000 frames per second with a resolution of 208×512 pixels. The exposure time was 10us. All the points were repeated five times in the experiment.

Table 2. Properties of diesel and gasoline.

	Diesel	Gasoline
Density@20°C (kg/m ³)	839.3	755.4
CN	52.6	---
RON	---	94.4
MON	---	82.7
LHV (MJ/kg)	42.9	43.5
Aromatics (v %)	29.6%	35.5%
T10 (°C)	214.8	59.7
T50 (°C)	266.1	107.3
T90 (°C)	333.6	160.2

The traditional simultaneous detection of gaseous and liquid phase often uses Schlieren or shadowgraph techniques. However, the high pressure and the hot heater inside the vessel result in a very strong turbulence in the visible area and large density gradients near the window (relatively colder than the test area center). This greatly deteriorates the image quality of Schlieren or shadowgraph (as shown in Figure 1b). In this experiment, a simpler setup was chosen: a near-parallel light source (a Xeon lamp with a parabolic back mirror) was used to provide backlight and the minimal aperture of the lens was used. It is found that the current method can provide better conditions for gas phase and spray edge detection (see Figure 1b). In the image, the liquid phase is quite obvious which is different with that of the Schlieren/shadowgraph. The boundary of the spray, which reveals the edge of the gaseous phase, has different features with the background, and it can be distinguished by a subtracting process (see the next section). The results shows that there is only a minor difference between Schlieren/shadowgraph and the current method. The maximum difference in gaseous phase area results is lower than 5.6% for 15 groups of comparisons. Considering the system errors and the errors in the imaging processing, the current method is acceptable as an alternative approach of Schlieren/shadowgraph under the current experiment conditions.

Imaging Processing

An in-house developed Matlab program was used for the image processing. The image sequences were converted to grayscale images and read into the computer. In order to reduce the disturbance from the background gas, the spray propagation was calculated using the following method:

Firstly, the absolute value matrix was obtained using image I_n to subtract image I_{n-1} ,

$$\Delta I_n = |I_n - I_{n-1}| \quad (1)$$

Then a threshold was applied to binarize ΔI_n (the difference area) to produce a binary matrix B_n . The reason for this step is that the adjacent images have very little differences with each

other thus the background is easier to remove. The accumulation of B_n gives the spray shape matrix (S_n) of the image I_n :

$$S_n = B_n + S_{n-1} \quad (2)$$

The two thresholds which distinguish the outer profile of the spray and the liquid boundary are a key factor which directly determines the accuracy of the results. In this study, the thresholds were validated by the side-illuminated image penetration results (which shows liquid phase) and the schlieren area results (which shows the gaseous phase profile) at lower back pressure. The data of 14 groups were compared to determine the two threshold values. Indeed the boundary detection faces the problem of invisible small droplets, but even the well-accepted schlieren method cannot avoid it. In order to realize a comprehensive comparison, thresholds were fixed for all the analyzed data in this study.

Notice that the liquid area may form a closed cavity inside the spray profile S_n because some parts of the liquid phase always have a grayscale constant value in the two images and the difference is zero. The cavity was then simply removed by applying the hole-filling algorithm, resulting in the final spray area matrix S_n' .

Next, the spray area of the image I_n was extracted with matrix S_n' , after which another threshold was used to identify the liquid phase within the spray profile. Then the liquid phase area and subsequently the gaseous phase area was determined. For the comparison, the two thresholds mentioned above in different cases are exactly the same, respectively. The gaseous phase penetration and liquid core length were measured along the center axis.

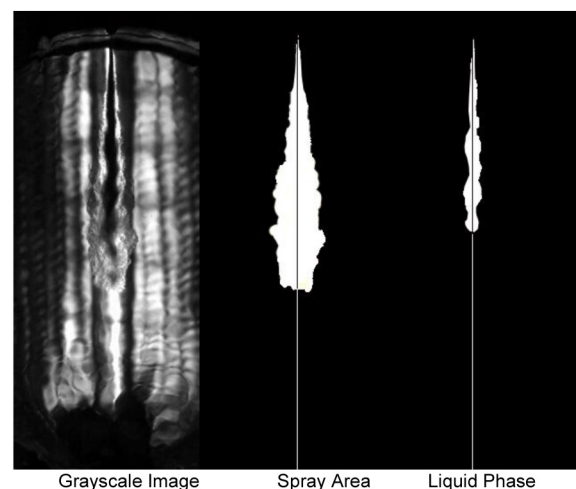


Figure 2. Image processing