A visual experimental research on spray characteristics of blended fuel with a large proportion of soybean oil methyl ester (SME)

Qian Wang, Chengcheng ZHANG*, Hengsong JI, Aiping Shi
School of energy and power engineering, Jiangsu University, China
zcc_cool@126.com and qwang@ujs.edu.cn

Abstract

As a biodegradable and oxygen-bearing fuel, biodiesel is valued extensively for its similar physical and chemical properties to fossil fuel. In recent years, biodiesel alternative application in diesel engine has been the great concern of researchers at home and abroad. Nevertheless, some key technologies have not been solved at present. Basing on synthetic consideration of economic and environment protection, alternative research of biodiesel in diesel engine focus on blended fuel with a certain proportion of biodiesel (volume ratio≤25%). Aiming at SME, transient injection process of blended fuel with different proportions of SME and diesel was investigated in this paper. High speed photography was adopted to test the transient evolution of the spray cone angle and growth process of spray penetration. The axial velocity, radial velocity and the distribution of particle size were studied using a phase-Doppler particle anemometer (PDPA) as well. Based on the visualization methods, the leading factors of blended fuel atomization were deeply investigated, especially for the heating blended fuel with a large proportion of SME.

The study shows that axial velocity is the main factor to affect the spray performances, which remarkably influenced the spray penetration and was also the vital factor of radial velocity. And the sauter mean diameter (SMD) of SME was 25% larger than the one of 0# diesel. It indicates that spray quality will get deteriorative obviously when mixing ratio of SME goes beyond 50%, and thermal enhancement before injection can make B75 take on good atomization performances and B75 exhibited a similar atomization quality to 0# diesel with the fuel temperature of 473K, but the influence of axial velocity on spray would be weakened simultaneously.

Introduction

Biodiesel is a sort of reproducible energy with especial advantages of combustion and good self-lubricity. With increasingly complicated and serious environmental problems, biodiesel's application in engines is a promising way to meet energy conservation and pollution reduction. In recent years, biodiesel has been paying much attention and research to copy with the depletion of fossil energy. Nevertheless, it is a task of top priority to overcome the bad atomization quality comparatively of biodiesel application in diesel engines, which is caused by differences in physical and chemical properties such as density, surface tension and viscosity intuitively.

In order to solve the problems, researchers have done a lot of contrastive work on spray performances between biodiesel and fossil fuel. In 2008, Ochoterena et al. [1] investigated the injection processes of RME (rapeseed oil methyl ester), GTL (natural gas to liquids) and fossil fuel using the optical diagnostic technology, and the results demonstrated the larger spray angle, smaller spray penetration for the high-viscosity fuel under the same conditions. However, in 2010, Xiangang Wang et al. [2] studied spray characteristics of biodiesels (palm and cooked oil) and diesel under ultra-high injection pressures (300Mpa) experimentally and analytically, and the thesis shows that biodiesels give longer injection delay, spray tip penetration and smaller spray cone angle, projected area and volume than those of diesel fuel. In2009, Su Han Park et al. [3] investigated spray atomization characteristics of an undiluted biodiesel fuel (SME) and diesel fuel and compared experimental results with numerical results predicted by the KIVA-3V code. In2010, through research, Kim et al. [4] argued that dimethyl ether (DME) showed the advantage and feasibility of spray relatively when compared to RME.

Furthermore, some researchers mix the fossil fuel with of biodiesel to partially substitute diesel fuel and achieve receptible atomization performances in the meanwhile. In2010, YU Jingzhou et al. [5] investigated spray atomization characteristics of DME/diesel blends in a diesel engine by Laser Size Analyzer (LSA). The thesis reveals that the droplet SMD decreased remarkably near nozzle, fuel spray break-up characteristics depend on fuel properties. When diesel blends with DME, spray atomization was improved greatly due to the decreased viscosity and DME flash boiling behavior. In2010, Ezio Mancaruso et al. [6] analysed the spray behaviour of first and second generation biodiesel in a Euro 5, common rail transparent diesel engine. GTL, SME and RME fuels have been used in blends at 100% and 50% in volume. A good agreement between the breakup times com-

*Corresponding author: zcc_cool@126.com

puted by means of the Hiroyasu and Siebers correlations and the ones from the experimental data has been found in two engine operating conditions in the paper.

In addition, PDPA and PIV technologies are applied to explore the microscopic characteristics of biodiesel spray frequently. In 2005, Lee et al. [7] built a device of fuel injection based on PDPA and revealed that biodiesel blends showed the semblable liquid penetration length and the larger SMD comparing with the fossil diesel. In 2006, Zhijun Wu et al. [8] studied the spray structure of oxygen-bearing fuel by means of PIV. It was found that the spray of oxygenated fuel showed an umbrella-shape structure, a lager spray angle, and a shorter spray tip penetration than diesel fuel. The spray of oxygenated fuel presented a weak large-scale heterogeneity and branch-like structure, a finer droplet, a stronger interface between fuel spray and surrounding gas, and a more violent vortical motion.

Presently, the researches are scarce in the spray process of heating fuel. A rare report is from Xu Zhaokun et al. [9]. In the paper, the results indicate that fuel can be vaporized in the flash injection by heating the fuel only up to 160℃. Another thesis that deserves attention is from Su Han Park et al. [10], who investigated, both experimentally and numerically, the spray behavior and atomization characteristics of DME at high fuel temperatures and under various ambient conditions based on a visualization system. It is indicated that the increase of the ambient gas temperature and fuel temperature induced the increase of DME overall droplet size. On the other hand, the ambient gas pressure slightly influenced on the overall SMD at a lower ambient gas temperature and lower fuel temperature, but the effect of the ambient gas pressure is significant at high ambient gas temperature and high fuel temperature.

To a certain extent, the results above reveal the atomization characteristics of biodiesel and demonstrate that different kinds of biodiesels have different spray behaviors. In the most of works, only with a small proportion of biodiesel can blended fuel show an acceptable atomization effect, and no effective methods have been found so far to fuel of pure biodiesel or blends with a large proportion of biodiesel directly in diesel engines. As such, aiming at blended fuel with different proportions of SME and diesel, this paper adopted high speed photography and PDPA system to investigate transient injection process on the visual experimental apparatus. It was investigated for feasibility of fuel thermal enhancement before injection to achieve highly-efficient application of blended fuel with a large proportion of biodiesel in this paper.

Experimental set-up and procedure

Experimental set-up

Visualization experimental test bench illustrated in Fig.1 was set up in terms of working features of diesel system. The injection system is mainly composed of high-pressure pump, common rail and electronic-control injector, which are all from DELPHI. The high-pressure pump (LBE type) was equipped with a variable frequency electromotor（Power, 5.5KW）, of which output speed can be modulated during 0～4000 n/min.The injector and common rail are controlled by a control and display system （CDS, TLD-09, Tailida Corp, China）, which was introduced to output the signals to solenoid valves for the cooperative work of injector and common rail. According to CDS, frequency and amplitude of driving signals can be regulated as needed, what's more, trigger signal was sent to PDPA and high speed camera to synchronize the injection starting and acquisition shooting by CDS. And nitrogen gas was utilized to pressurize the constant volume bomb from the ambient value to 0.3Mpa.

This paper adopted sensors to test fuel pressure and temperature in common rail, fuel temperature in the tank and rotation speed of the pump.Sensors for common rail was self owned, PT100 and H3-D8NK were chosen to be the temperature transmitters for fuel in tank and rotation speed transmitter for the pump respectively. All data results can be displayed on the LED screen of CDS.

A high speed camera (MotionPro-TM10000, REDLAKE MASD Corp, USA) equipped with an image processing and analyzing software was used to capture the spray images. The imaging speed was set to 10,000 frames per second and the pixels of images were 1280×1024. Fig.2 shows a spray image acquired by high speed camera in the experimental condition in this paper.

The PDPA system (Dantec Corp, Denmark) adopted in this study can realize real-time measurement of size, velocity and concentration of particles (especially for spherical particles), droplets and bubbles in both liquid and gas flow in using of the Doppler Effect. Fig.1 shows the basic structure of the PDPA system, which configures with a 320MW water-cooled argon ion laser, a laser coupler, an RSA signal processor, a data processing system, a laser emitter and receiver and so on. The PDPA system can be used to achieve precise characteristic parameters of the particles measured on transient injection and real-time automatic processing. Based on the Lorenz-Mie theory, the size of the particle is proportional to the phase difference and can be obtained by processing the phase difference between probes in the PDPA system. When a monochromatic laser beam produced by water-cooled argon ion laser goes through the fiber coupler, six beams with three colors (green, blue, purple) monochromatic light was generated and then coupled into the emission probes. Then the droplet’s velocities in different directions and SMD are measured by monochromatic beams emitted from different probes. The six beams will converge at one point and transform into a corresponding signal when through two beams of monochromatic light with a certain phase difference. And 3D velocity and SMD can be obtained by processing the electrical signals acquired from the photoelectric converter. Finally, measured data of the entire biodiesel spray can be obtained by using 3D automatic displacement system.

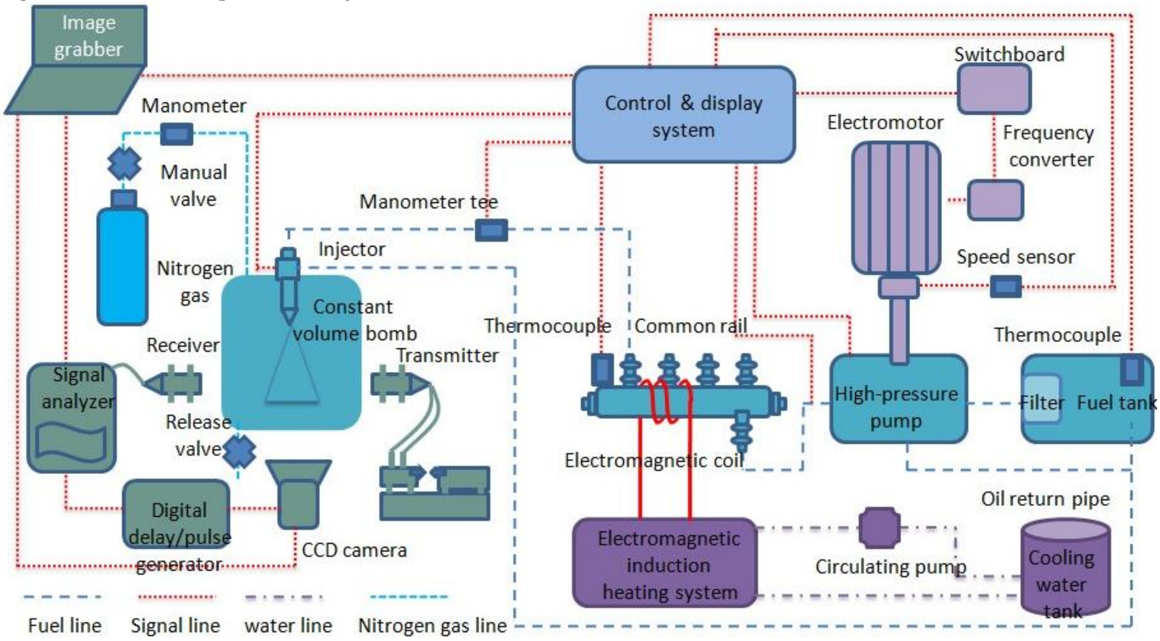

Figure 1 Schematic of the spray visualization system with a fuel heating device.

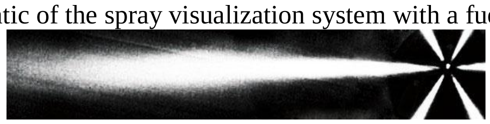

Figure 2 A spray image acquired by high speed camera of B0.

Fixed-point measurement was used in the PDPA experiment, and the whole spray must be divided into grids. Then the processing software of the system can process the data acquired from each grid node. SMD is chosen to estimate the size of particles in PDPA system in this study. Fig. 3a shows the PDPA grid point distribution of the fuel spray. The whole spray is divided into about 30 test points including 8 test points on the axial direction. When the test points have been specified, the PDPA system could acquire data automatically in accordance with the predetermined order, that is, from the point closest to the nozzle orifice to the farthest point. Fig. 3b shows the particle size distribution in the spray. The PDPA system shows the accurate measurement of particle size and velocity as illustrated in Fig. 3c.

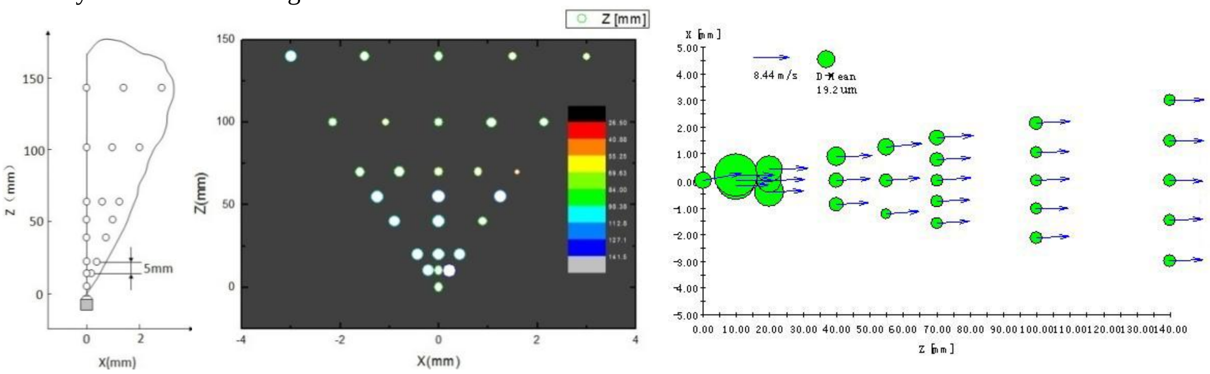

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Figure 3 PDPA grid point distribution (a), spray particle size distribution (b) and axial velocity and size distribution (c) in this paper.

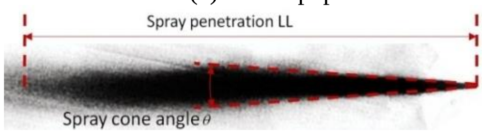


Figure 4 Definitions of liquid spray penetration and spray cone angle.

The fuel heating module uses a thinking of high-temperature-high-pressure rail, and the high temperature condition needed in the fuel injection is generated in high pressure common rail. Electromagnetic induction heating equipment is used to heat the fuel to obtain enough and steady high temperature and high pressure blended fuel in the common rail before injection. As shown in Fig.1, the heating module is placed on the downstream of the high-pressure pump to avoid its invalidation caused by low viscosity of high-temperature fuel. This heating method is also helpful to raise fuel pressure in the rail. And the large capacity of the rail ensures sufficient high temperature fuel and reduces the mechanical load of the high-pressure pump. TX-15 high-frequency electromagnetic induction heater is used to heat the fuel. Fig. 4 shows the heating method for electromagnetic induction coil in the experiment. The non-contact heating process of the rail ensures the safe and efficient fuel feed. The heater is equipped with a cooling water circulation system with the discharge of 4L/min. The maximum power oscillation of the heater is 15KVA. And the heating current and operating frequency are 200A~600A and 50Hz, respectively.

Experiment schemes

The atomization characteristic of SME blends is mainly studied in this paper. The comparison of physicochemical properties between SME and 0# diesel is summarized in Table 1. As is shown in the Table, compared with 0# diesel, SME has higher density and kinematic viscosity, lower calorific value and equivalent air-fuel ratio, and the ignition temperature of SME is apparently higher than that of 0# diesel.

Table 1 Physicochemical properties of SME and 0# diesel.

Parameters	Soybean Oil Methyl Ester	0# diesel
Density / kg/m ³	881	825
Kinematic viscosity / mm ²/s	4.47	3.0~8.0
Cetane number	51.2	≥49
Acid value	1.24	≤0.8
Oxidation stability	2.9	——
Low calorific value / MJ/kg	33.6	42.5
Equivalent air-fuel ratio	12.9	14.3
C/H ratio	8.73	6.56
Oxygen content / %	13.5	0
Ignition temperature / K	628.5	472~493

A set of DELPHI fuel injection system applied in a 4-cylinder engine is used in this study. The injector has 6 holes with the diameter of 0.28mm. The fuel injection system provides injection pressure up to 180MPa. In this experiment, an injection pressure of 20MPa is used, and injection frequency is set to 12 H_z. Table 2 shows the other parameters in detail.

Table 2 Parameters of fuel injection system and experimental conditions.

Injection parameters		Experimental conditions	
Nozzle orifice/ r/mm	6×0.28	SME fraction BX / %	0;25;50;75;100
Single injection duration / t_s/ms	5.2	Fuel temperature / T_s/K	293;353;413;473
Injection pulse / t_i/ms	78.2	Back pressure / P_a/MP_a	0.3
Injection pressure / P_S/MP_a	20	Ambient gas	nitrogen
Injection frequency / f /H_z	12	Ambient gas temperature / T_a/K	293
Oil pump rotation speed / N/n/min	900	Oil return coefficient ε	50%

The spray atomization characteristics of 0# diesel and SME mixtures with different ratio are studied in this paper. BX in Table 2 represents different proportions of the blended fuel, in which the X is the volume ratio of SME calculated by percentage. Five different blends were used (B0, B25, B50, B75, B100). The back pressure is 0.3MPa, and the ambient gas in the constant volume bomb is nitrogen of 293K. Four different values of fuel temperature of B75 were tested: 293K, 353K, 413K and 473K. The error of fuel temperature in the rail heated by electromagnetic induction heater is ±1K.

Results and discussion

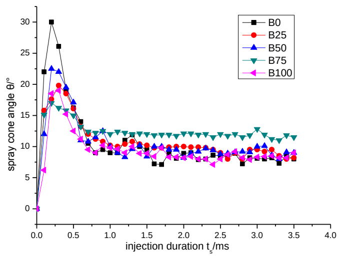
Macroscopic characteristics of transient spray

There is no clear agreement about the standard definition of spray cone angle and spray penetration in present literatures. Fig. 2b shows the output characteristics defined in this paper. As can be seen, spray penetration (liquid length, LL) is the maximum distance which liquid-phase spray can reach and the spray cone angle is formed by two rays which along the edge of the liquid-phase spray.

Table 3 Characteristic value of spray cone angle.

Parameter	B0	B25	B50	B75	B100
Hump height θ_h	30	19.8	22.5	17.0	19.0
Mean value after stabilized θ_a	8.6	9.5	9.4	11.8	8.7

In this study, the spray cone angle of blended fuel shows the value variation like a hump at first and then tends to be relatively stable with the duration of the injection after the opening of the injector solenoid valve. Spray cone angle increases rapidly after the start of injection and then decreases sharply, from which the hump effect comes. Blended fuels with different mixing ratio have approximately the same hump duration of around 0.75 ms but different hump heights, θ_h. And the stabilized spray after 0.75 ms display different spray cone angle to some extent. The average of stabilized spray cone angle after 0.75 ms and the hump height are summarized in Table 3. As shown in Table 3 and Fig. 5a, the higher the hump height in spray process is, the lower the average of stabilized spray cone angle after 0.75 ms will be. As far as B75 is concerned, it has a lowest hump height, 17.0 °, but a mean value up to 11.8 ° when stabilized. Regarding to B0 (0# diesel), the maximum value of hump height is 30 ° with the lowest mean value of only 8.6 ° after stabilized. It is necessary to emphasize that B100 (pure biodiesel) has a lower value of both θ_a and θ_h.



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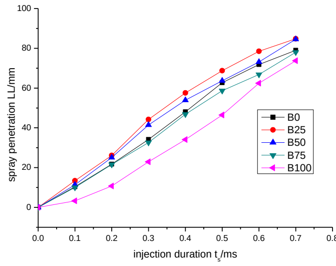

5b

Figure 5 Spray cone angle (a) and spray penetration (b) with the increase of the injection duration.

According to the analysis, the hump effect of spray cone angle in blended fuel was mainly due to the ambient gas condition that can favor the atomization in both axial and radial direction of the initial stage of the injection. On the stage the interaction of fuel and ambient gas is strong, which means the pressure fluctuation between gas and liquid phases is the dominant factor of the atomization. As illustrated in Table 3 and Fig. 5a, the hump height of B0 which has the minimum density is maximal, while B100 and B75 with the larger density have the smaller values. In addition, the random instability inside the nozzle holes at the opening of solenoid valve may affect the hump phenomenon, too. The result shows that the pressure fluctuation between gas and liquid phases determines the value of θ_h and the nozzle parameters and other injection parameters determines the duration of the hump.

Fig. 5b shows the spray penetration with the increase of the injection duration. It is obvious that the transient growth rate of spray penetration is consistent among blended fuels. The penetration decreases in turn along with the increase of the SME volume fraction at the same time. Due to the hump effect, the fuel atomization process consumes different momentum, and the residual momentum causes the difference of spray cone angle and penetration after 0.75ms.

Microscopic characteristics of transient spray

The test of spray microscopic characteristic is based on measurement of stabilized atomization processes. And the data are acquired at 1.2ms after the opening of the injector solenoid valve. In this paper, V_z refers to the droplet velocity along the Z-axis and V_x is the velocity along the radial direction of spray.

Fig. 6a shows the variation of axial velocity of the blended fuel droplet with the increase of Z-axis location. And the axial velocity at the orifice outlet is mainly determined by absolute pressure difference, geometric dimension of injector and physicochemical characteristics of fuel, which directly affecting the spray characteristics, especially the spray penetration. And it is one of the dominant factors that affects the formation and distribution of vortex in in-cylinder mixing process. As can be seen in Fig. 6a, under the same injection conditions, the proportion of blended fuel has an obvious influence on the axial velocity near the orifice outlet. B0 has a higher axial velocity than that of B100, and B25 has the largest axial velocity while B50 has the smallest. The difference of axial velocities tends to be stabilized until Z location is up to 20mm.This chiefly because under the conditions with the identical injection pressure and injector geometric dimension, the turbulence in nozzle holes is different for the different extrusion of surface tension, which is the major of the difference of axial velocities.

The variation of the radial velocity of the blended fuel droplet with the increase of Z location is demonstrated in Fig. 6b. Before the Z location 20mm, it exists obvious difference up to orders of magnitude of the radial velocity, which shares the same variation tendency with axial velocity. It is considered that large density differences of blended fuel with different ratio leads to the difference of pressure fluctuation intensity between vapor phase and liquid phase, which affects the break-up and evaporation in the atomization process further.

The difference of the radial velocity of blended fuel results from the interaction between fuel and ambient gas which is mainly determined by spray momentum along the axial direction, that is, there is a close relationship between axial velocity and radial velocity.As presented in Fig. 6a and Fig. 6b, the tendencies of axial velocity and radial velocity are approximately identical. Both the axial and radial velocities become stabilized after a tiny increase. And the larger axial velocity is, the larger the corresponding radial velocity is. The largest axial velocity and the largest radial velocity near the orifice outlet are both from B25, and the smaller velocities belong to B50 and B100 while B0 and B75 are at an intermediate level. As demonstrated above, the axial velocity near the orifice outlet is mainly determined by absolute pressure difference, geometric dimension of injector and physicochemical characteristics of the fuel. After blended fuel injected at a high pressure, there are lots of momentum transfer between spray and ambient gas, which enhances the interaction between droplets and ambient gas along the x direction. The fuel droplet distribution is directly affected by the increase of radial velocity, which is the main factor of formation of spray cone angle. For example, there is a little momentum exchange between B100 spray near the orifice outlet and the ambient gas along the axial direction. So it remains higher axial velocity even at Z=140mm location. And radial velocity and spray cone angle of B100 are comparatively small and the spray penetration is the longest. The tendency of the spray cone angle depicted in Fig. 5a agrees well with that of radial velocity.

The variation of the SMD on the Z-axis with the increase of Z location is presented in Fig. 6c. The SMD of SME is evidently larger than that of 0# diesel with the difference of about 50% and the SMD of blended fuel is among them, which are consistent with the result gained by high-speed digital camera.

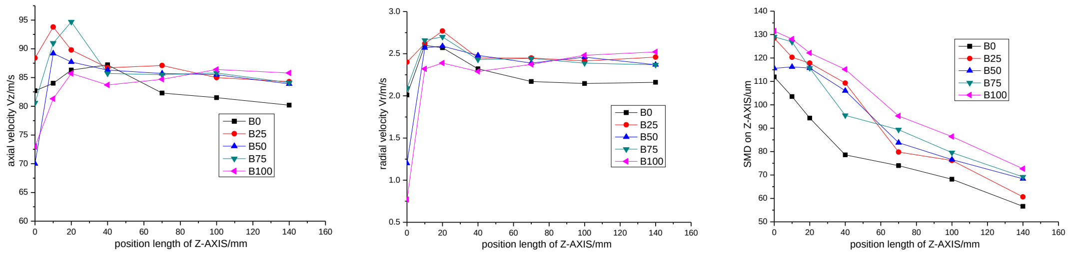

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Figure 6 axial velocity, radial velocity and SMD in the spray axis against Z location.

A histogram of the droplet number with different SMD in the spray field is illustrated in Fig. 7. According to this figure, a majority of blends droplets are concentrated on SMD of 5~ 25um and the droplet number with SMD beyond 40um is very few. As far as B50 is concerned, the number of smaller droplets with SMD between 4~10um is relatively more, and among them the droplets with SMD around 8um are at the quantity of 180. While regarding to B75 and B100, the number of droplets with SMD between 6~14um is relatively more and among them the number of small-diameter droplets are few. Total SMD converted by the number of the all droplets in the spray field according to Fig. 7 are listed in Table 4. The total SMD of B0, B25 and B50 are smaller but the total SMD of B75 and B100 are comparatively larger, which proves the deterioration of atomization when the proportion of SME is over 50%.

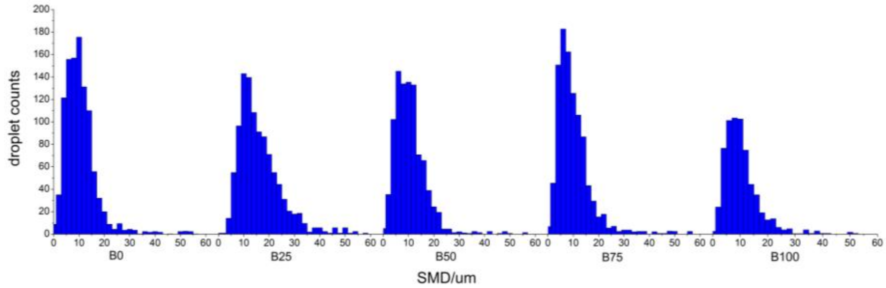

Figure 7 Histogram of the droplet number with different SMD in the spray field.

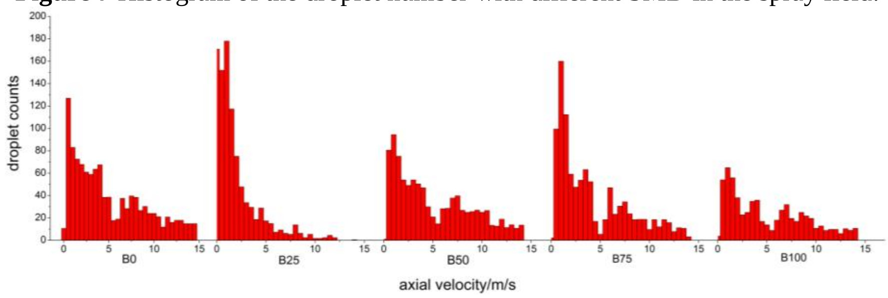

Figure 8 Histogram of the droplet number with different axial velocity in the spray field.

Based on the significance of axial velocity, a distribution statistics of droplet number with various axial velocities is carried out. As illustrated in Fig. 8, the existence of negative values is mainly because low intensity vortexes are formed in the spray. With respect to B0, the quantity of droplets with velocity 0~3m/s is large, and a few droplets have a velocity over 5m/s. As far as other cases concerned, axial velocities of a great part of droplets are during the 0~4m/s. Still quite a few droplets are distributed during the 5~15m/s. It can be seen from the figure that comprehensive momentum transfer happened between diesel or blended fuel with small proportion and ambient gas. However, too much proportions weaken the effect of momentum transfer, which results in incomplete atomization. In particular, compared with blended fuels, diesel has smaller viscosity and density with the pressure fluctuation and the shear wave intensity on the surface of the spray increased.

Table 4 Mean axial velocity and total SMD in the spray field.

Parameters	B0	B25	B50	B75	B100
Mean axial velocity	84.6	88.2	83.9	86.8	82.1
Total SMD(Mean D32)	21.2	20.6	16.6	25.8	26.3

It should be noted that the SMD variation shows an inconsistent increase with the increase of SME proportion. The irregular variation of SMD in B25, B50 and B75 can also be seen in values of spray penetration, spray cone angle, axial velocity and radial velocity. It is inferred that the disparity of atomization may caused by different droplet structure of different blended fuels. This paper believes that the SME is wrapped by 0# fuel in the case of droplets of B25, while 0# diesel is wrapped by SME in the case of B75, too. With this assumption, the liquid on the droplet surface has different properties, which results in disorder atomization behavior. Differing from B25 and B75, the B50 has a structure of SME and diesel wrapped in each other, as shown in Table 4, a better atomization is indicated. The correctness of the inference remains the further study.

Atomization characteristics of the heating B75 fuel

On the base of sections above, in order to achieve better atomization of blended fuel with a large proportion of SME, a visual experimental research on B75 under thermal enhancement condition was carried out. The experimental condition is unaltered except the fuel temperatures (293k,353K,413K,473K).

The variation of spray cone angle, SMD on the Z-axis and spray penetration after spray stabilized of B75 at different temperatures are illustrated in Fig. 9. It shows that the hump phenomenon becomes more apparent with the increase of fuel temperature, while a fall can be observed in average stabilized spray cone angle.This is chiefly caused by the change of the surface tension and density as the fuel temperature rising. Thus it weakens the constraint of surface tension on breakups, and the gas-liquid density ratio increases along with the density decreasing of the droplets. All of these are helpful to rapid atomization and evaporation of high temperature droplets. The obvious decrease of SMD on Z-axis as the increase of fuel temperature is presented in Fig. 9b.

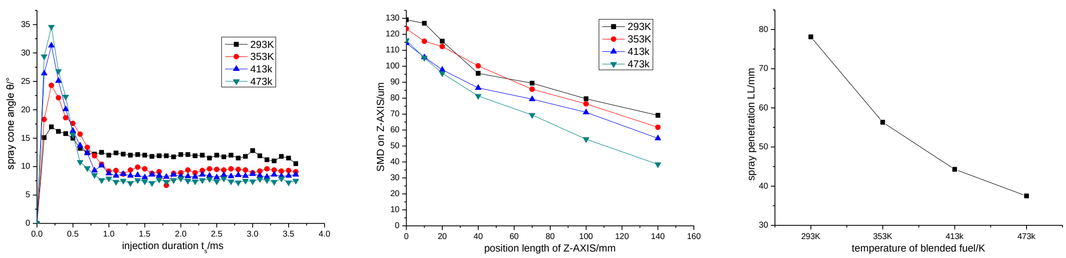

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Figure 9 Spray cone angle, SMD on the Z-axis and spray penetration of B75 at different temperatures.

Table 5 Mean axial velocity of droplet and SMD average of B75 at different temperatures.

Parameter	293K	353K	413K	473K
Mean axial velocity	86.8	84.2	73.3	65.7
Mean value of D32	25.8	22.5	20.7	18.4

As can be seen in Fig. 9c, the stabilized liquid-length decreases gradually along with the increases of fuel temperature, and the higher the fuel temperature the more remarkable the reduction trend. Apparently, with the droplet temperature rising, the liquid-phase duration will become shorter, and vapor-phase in the droplet frontier becomes richer, so droplet velocity decreases rapidly, which is consistent with the tendency of the mean axial velocity of droplets in Table 5. Therefore, the spray penetration decreases accordingly. Before droplets reach at the maximum distance, the break-up, atomization and the mixture with entrained air will enlarge the whole mass and volume of the frontier droplets group. The higher the temperature, the quicker the evaporation, and then the more the amount of entrained air. And the spray penetration reduces accordingly for the increase of the resistance. The SMD average with different temperatures of B75 at 1.2ms can be seen in Table 5. The rising fuel temperature plays a vital role in prompting droplet evaporation, so the SMD decreases rapidly and the number of droplets increases quickly as the fuel temperature grows.

Conclusions

As for spray cone angle of blends, the higher the hump height, the lower the stabilized mean value in this transient injection. The hump height becomes smaller when the percentage of SME increases. And the higher fuel temperature can favor the hump effect. The hump height increases when fuel temperature increases but fuel temperature and proportion has a subtle influence to the hump duration.

The axial velocity plays a vital role in spray penetration. And it is also the decisive factor for the radial velocity. The variation of both velocities are approximately identical. Researches indicate that the larger the axial velocity, the larger the corresponding radial velocity and the spray cone angle. When the proportion of SME is more than 50%, the axial velocity decreases obviously. After thermal enhancement, the fuel evaporation is improved because of decrease of the surface tension on the high temperature surface and the increase of gas-liquid density ratio. Then the axial velocity decreases apparently and its impact on the spray velocity field become weakened.

The SMD atomized by SME is larger than that of 0# diesel at the difference of about 25%. The atomization would be exasperate when the proportion of SME is over 50%. And it can display a better atomization of B75 by heating the blended fuel, which is close to 0# diesel with the temperature of 473K.

Acknowledgements

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