Visualization Test on Spray Impingement of CTL Fuel

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Abstract. At present, most of the researches on spray characteristics are focused on free injection cases. This paper researches the spray impingement phenomenon of CTL fuel in a visualization test system by high-speed photograph technology and discusses the influences of ambient pressure and wall distance on impingement process. The results show that the wall diffusion radius increases linearly, the entrainment height increases firstly and then keeps stable gradually and the velocity of spray tip decreases rapidly with CTL continuation injection. When the ambient pressure increases, impingement wall time delays and initial impingement radius increases, and it is the same situation with increasing wall distance. Simultaneously, increasing ambient pressure can reduce the spray diffusion radius and raise the entrainment height, while it displays an opposite trend with increasing wall distance. The contrast test results of spray wall-impingement for both of two fuels show that CTL fuel exhibits a slightly later spray impingement wall, a shorter spray diffusion radius and a thinner entrainment height than No.0 diesel. The research results have a certain reference value to guide the application of CTL in diesel engines.

Due to the restriction of combustion chamber geometry, the fuel spray impingement plays a leading role in the mixture formation which is the basis of thermodynamic process in the engine cylinder, especially for small and medium-sized diesel engines. Spray impingement shows significant advantages in enhancing the spray diffusion, accelerating the mixture forming and improving the engine performance. However, the film on the wall results from fuel impinging will cause the secondary atomization which is an important reason for the higher HC and PM emission. Therefore, the characteristic of fuel spray impingement directly determines the subsequent combustion quality and emissions quality [1~4].

The synthetic oil from coal (Coal-to-Liquids, CTL), is an excellent cleaning alternative fuel for diesel, produced by Fischer-Tropsch synthesis method in the early 20th century. Compared with the ordinary diesel fuel, the CTL has a higher cetane number, a lower process temperature, a lower density and a lower viscosity property, etc. International research for CTL as substitute fuel in a compression-ignition engine begins at the end of the 20th century. In recent years, the researches for application of CTL in engine include the fuel spray, combustion, emissions, applicability and life cycle assessment, etc.

The different physical and chemical properties about CTL and ordinary diesel, including oil density, viscosity, surface tension and volatile, lead to a great different fuel spray process each other. At present, most of the researches on spray characteristics about CTL are focused on free injection cases[5~7], but on wall impinging related research is rarely. In the study on the basis of the free spray characteristics of CTL[8], the author further researches the spray impingement behavious of CTL in a spray visualization test system, focusing on ambient pressure (Pb) and wall impinging distance (Z) influence on vertical impingement characteristics of CTL fuel, and compares it with ordinary diesel fuel spray impingement. This research result will provide a useful theoretical foundation to the development of CTL fuel spray theory and will have a certain reference value to guide CTL application in diesel engine.

1 Fuel properties

The main physical and chemical properties for CTL and No.0 diesel (countries Ⅲ) used in spray test are shown in table 1.

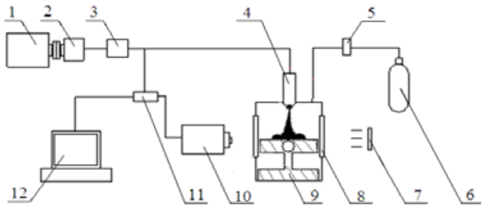
Table 1: Properties of CTL fuel and No.0 diesel（20℃）

Features	CTL fuel	No.0 diesel
Density/g·cm^{-3}	0.76	0.831
Viscosity/mm^{2}·s^{-1}	2.114	3.525
Flash point (held)/℃	52	68
Solidifying point/℃	-2	＜0
Cold filtration point /℃	2	-4
Distillation range (T95) /℃	319.3	331.3
C content (quality) / %	85	86
H content (quality)/ %	＜15	＜14
S content (quality) / %	＜0.00005	＜0.031
Aromatic hydrocarbon (volume) / %	0.1	34.68
CN values	74.8	50
Low calorific value /MJ·kg^{-1}	43.75	42.6

2 Test apparatus and test conditions

2.1 Spray visualization test system

The spray visualization test system mainly includes the constant volume spray device, high pressure fuel injection device, jet impact platform, schlieren optical system, signal control system and image acquisition system. Test system layout is shown in figure 1. The equipment parameters are shown in table 2.



1-frequency generator; 2-high pressure pump; 3-solenoid valve; 4-injector; 5-relief pressure valve; 6-high pressure nitrogen; 7-slit lamp; 8-constant volume chamber; 9-jet platform;10-high-speed CCD camera;11-trigger unit; 12-computer

Fig.1: Schematic diagram of visualization test system

Table 2: Experimental apparatus and parameters

Apparatus	Model	Remark
high-speed CCD digital camera	MotionXtra HG-100K	resolution of 320 x 320 pixels, the highest speed for camera 10000s^{-1}
schlieren device	WCL	Made in China
xenon lamp light source	—	Rated power 500W
high pressure pump	Type A pump	Bosch company
frequency generator	YVP100L 1-4	Made in China，rated power 2.2kW，the adjustable speed range is 100r/min-1500r/min
solenoid valve	WS2-1	Made in Germany，working current 0-18A
constant volume chamber	homemade	The highest pressure is 10 MPa
platform	homemade	Smooth surface, size of 80mm×80mm, adjustable height is 10mm-60mm;

In the visualization test system, the cast iron constant volume chamber has a cylindrical cavity which is connected with a top cover, in the center of which the fuel injector is installed. And both of quartz glass windows are arranged opposite in the constant volume chamber. Also, the high pressure pump is driven by a frequency generator which is controlled by an ECU. Meanwhile, the fuel is injected from a single-hole nozzle of which the opening pressure is adjustable and then impinges upon the platform vertically. Afterwards, the schlieren images of fuel spray development are recorded by a high speed digital camera. The parameters of the high pressure fuel injection system are shown in table 3.

Table 3: Parameters of fuel injection system

Project	Parameter
Injector type	Single-hole nozzle
Opening pressure of nozzle	23
Orifice diameter of nozzle	0.29
Length to diameter ratio of nozzle	3.45
Injection pressure	75
A single injection quantity	46.7
Injection duration	4.4

2.2 Test conditions

In this paper, the fuel spray vertical impingement test is carried out on the condition that there were airflow disturbances and constant temperature in constant volume chamber. Furthermore, the ambient pressure of injection is adjustable by adjusting the pressure of nitrogen which is filled from a high-pressure nitrogen cylinder. The cases of specific test conditions such as table 4.

Table 4: Test conditions

Project	Parameter
Speed of frequency generator/r.min-1	1330
Temperature of constant volume device/ K	300
Fuel temperature/K	300
Ambient pressure of inject/ MPa	1、2、3
Impinging distance/ mm	45、35、25

Setting the speed of oil pump after completing the schlieren optical path, then shoot the whole process of single injection through the high-speed photography method, and the spray image data is input through Labview software and is stored in the computer. Average a set of images data in order to obtain more reliable test results and then the spray impingement characteristics are researched quantificational based on Matlab software which is developed by oneself [9]. Light scatterance due to broken droplets results in difference for spray outline between test image and actual image, which will be ignored in test analysis.

3 Test results analysis

3.1 Spray bump wall parameters

Macro parameters for bump wall spray include spray bump angle α, impinging distance Z, spray diffusion radius R and spray entrainment height h, which are shown in figure 2. In this test, the spray bump angle α= 90°.

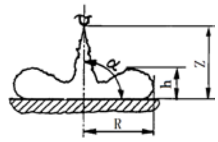


Fig.2: Definition of spray wall-impingement

3.2 The analysis of Injection back pressure

Figure 3 shows the contrast of the CTL fuel characteristic parameters in different injection back pressure with the bump wall distance Z=45mm.The abscissa t uses fuel spray moment (the moment of the first spray droplet appears in the nozzle) as zero time and uses spray bump wall moment in various operating conditions as the record of the first time. This definition is suitable to behind all.

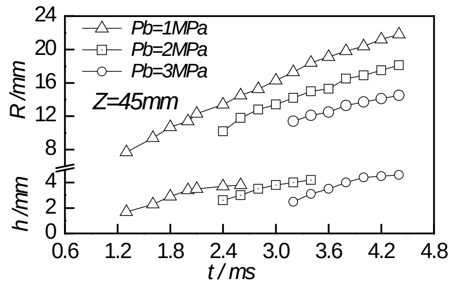


Fig.3: Back pressure influence on spray diffusion radius and spray entrainment height

Figure 3 shows the linear growth tendency between the CTL fuel diffusion radius along the wall and the injection time. Spray entrainment height along with continuous injection time increases slowly and tends to be stable. Under the same bump wall distance, with the increasing of injection back pressure, CTL fuel bump wall moment gradually delays, the initial bump radius increases gradually, the spray entrainment height continuously increases, the spray diffusion radius continuously decrease. This is because the increasing back pressure increases the density of the spray environment, thus increases the momentum exchange between environment gas and spray droplets, thereby causing the spray oil beam kinetic energy loss increases, so the spray throughout the same distance need more time. And under high injection back pressure, the disturbance between spray oil beam and the environment medium represents more strongly, this makes the horizontal extend trend increase, so the spray bump point radius is also bigger, this means the area between bump wall droplet with the surface is larger, makes the evaporation of the droplets and the entrainment of the gas with the outside gas more easily, eventually lead to maximum entrainment height increasing, along with increasing back pressure.

Figure 4 shows that the t back pressure effect on spray distal development speed. Definition:

$$v = R/(t - t_W) \qquad (1)$$

v:spray distal development speed; R: spray diffusion radius; t :the injection duration time; t_W:spray bump wall moment.

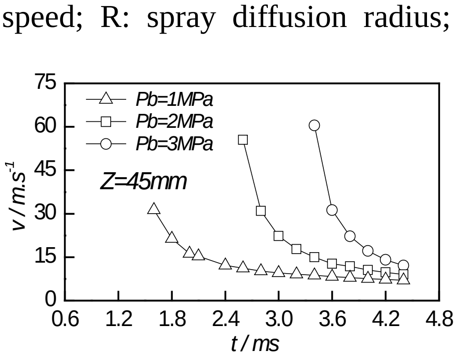


Fig.4: Back pressure on spray distal development speed

Figure 4 shows CTL fuel after bumping wall makes spray distal development speed slowed sharply, due to the effect of environmental resistance, although under the high injection back pressure spray distal development speed is larger, the speed after bumping wall is attenuated quickly, Coupled with the high back pressure with shorter duration time, so this causes spray diffusion radius is smaller.

3.3 The analysis of bump wall distance

Figure 5 and figure 6 shows the *Pb*=3MPa, with different impinging distance CTL fuel spray bump wall characteristic parameters change with the injection time.

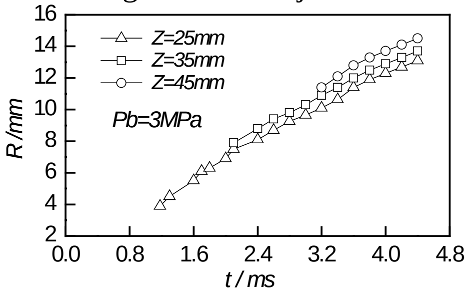


Fig.5: Impinging distance influence on spray diffusion radius

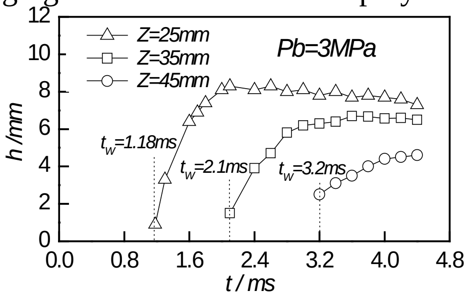


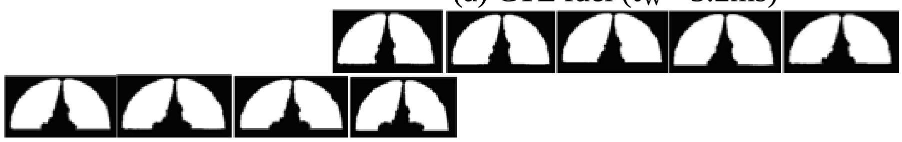
Fig.6: Impinging distance influence on entrainment height

Figure 5 and figure 6 show that the larger impinging distance, the later bump wall moment and the larger initial bump wall radius, especially the influence of the impinging distance on spray entrainment height is more remarkable. Under the given injection back pressure, about 0.8ms after CTL fuel spray bump wall, the entrainment high reaches stable; Under the same injection back pressure, along with the increase of impinging distance, CTL fuel spray diffusion radius increases and spray entrainment height continuously decreases. Because that the spray radius increases after distal impinging makes spray droplets and the wall have a larger contact area, spray spreads easily, so spray diffusion radius gradually increases; And the droplet momentum of distal impinging wall is relatively small, the rebound and splash of spray beam are abate, so spray entrainment height decreases. Thus we can infer that bump wall moment and impinging distance are the key parameters to form an excellent mixture gas. So in the CTL fuel engine development process, considering of spray bump wall, we should reasonably design the structure of combustion chamber, the layout of fuel injector, the form of inlet tube and the determination of injection time, in order to fully play the beneficial role of CTL fuel bump wall and better promote the formation of homogeneous mixture gas.

3.4 Compared with the traditional diesel spray bump wall characteristics

In order to illustrate the impinging characteristics of CTL fuel and diesel, figure 7 shows the spray beam development photos of the CTL fuel and No.0 diesel from the start bump wall to the end of spray through Matlab software processing (the time interval is 0.2ms).

(a) CTL fuel (t_W =3.2ms)



(b) No.0 countries Ⅲ diesel (t_W=2.8ms)

Fig.7: The development on spray vertically impinging wall (Z=45mm、P_b=3MPa)

Figure 7 shows that under the condition of the given spray, the bump wall moment of CTL fuel is late nearly 0.4 ms than No.0 diesel. Both fuel injecting to the wall form the wall jet and spread around; With the accumulation of bump wall oil beam, when wall jet kinetic energy can not drive the accumulation of fuel quantity, collision fuel begin to spread into space. Can be found directly from the table, the oil and gas accumulation that CTL fuel spray bump wall formed is less than No.0 diesel, this means more CTL fuel is distributed in the impinging platform and spray chamber, CTL fuel bump wall tendentiousness is small.

Figure 8 makes the quantitative analysis of spray development process. The figure shows that CTL fuel and traditional diesel spray bump wall law is similar, but under the same bump wall injection condition, the bump wall moment of CTL fuel is late, the initial radius of impinging point is larger, the diffusion radius of the spray beam along the wall and the entrainment height are smaller. Figure 9 shows the test condition, during the injection duration time after the fuel dump the wall, CTL fuel averaged diffusion radius is 13.1 mm along the wall, is smaller about 25% than that of diesel, spray entrainment averaged height is 3.8 mm, is smaller about 27% than No.0 diesel .

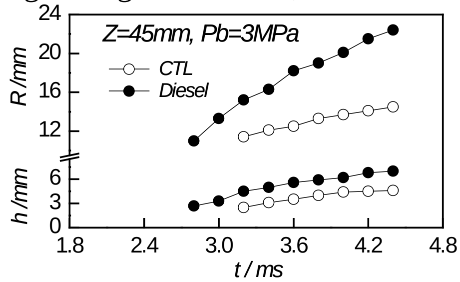


Fig.8: Spray bump wall parameters contrast on CTL fuel and 0 # diesel

Fuel viscosity and surface tension are important factors affecting the spray characteristics [10]. The viscosity and the surface tension of CTL fuel are less than diesel, this is more conductive to the breaking of fuel jet flow and the vaporization and enhance spray head and air entrainment effect, which will further reduce the size of the jet atomization droplets, while smaller droplets size have smaller momentum and windward area, thus increasing the motion resistance and making horizontal extension before spray bump wall also increase, eventually lead to the bump wall moment of CTL fuel is later, and the initial radius of impinging point is also longer. In the same way, the larger motion resistance limits the diffusion along the wall after spray bump wall, so the diffusion radius of the CTL fuel is smaller than that of diesel; And relatively small bump wall momentum of CTL fuel lead that the rebound and splash of spray beam are weaker, so the entrainment after spray dump wall is smaller than traditional diesel.

4 Conclusions

(a) With continuous injection time, the diffusion radius of CTL spray beam along the wall presents linear growth trend, spray entrainment height increases slowly to ultimate stability, spray distal development speed gradually decay.

(b) Injection back pressure and bump wall distance are the key parameters to form a good mixture gas. Improving injection back pressure will increase the adverse effect of environment gas on the CTL spray momentum, this makes its bump wall time delay, bump wall initial radius increases, spray distal development speed after dumping wall attenuates, spray entrainment height increases, the largest spray beam diffusion radius decreases; Increasing bump wall distance can reduce the dump wall momentum of spray particle and delay CTL fuel bump wall, increase the dump point radius, Furthermore, the diffusion radius after spray beam dump wall gradually increase and spray entrainment height is smaller.

(c) CTL and diesel have a similar spray dump law, but under the same injection condition, the bump wall moment of CTL is later, the diffusion radius of the spray beam after the fuel bumps the wall and the entrainment height are smaller.

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