Spray Atomization Characteristics of the Biodiesel of Different Blending Ratio

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Abstract
Mainly to the physico chemical characteristics and spray characteristics of biodiesel mixed with diesel fuel, a sequence of experiments are carried out on spray characteristics of biodiesel with different mixing ratios. By Malvern laser particle size analyzer, Sauter diameter and liquid drops size of cumulative volume distribution are respectively detected when mixed fuels with different mixing ratios biodiesel are in away from nozzle 200mm, and 300mm, and 400mm, and 500mm. the effects of biodiesel with different mixing ratios on atomizer and spray angel are analyzed and the variation of spray atomization with the development of injection beam are analyzed. It is indicated that spray angle will decrease when biodiesel fuel is added to the diesel, and With the increasing of biodiesel mixing ratio, the spray angle of mixed fuel will be declining. With the increasing of injection beam distance of the biodiesel with different mixing ratios, the Sauter diameter of the fuel spray shows an increasing trend. In particular, the Sauter diameter has its minimum and the uniformity of droplet size distribution reaches the maximum when the biodiesel mixing ratio is 20%. In brief, the spray automation is relatively good when the biodiesel mixing ratio is 20%.

Key words: Biodiesel Fuel Spray Atomization, Spray Angle, Sauter Diameter, Cumulative Volume Distribution.

1. INTRODUCTION

Under the pressure of the energy crisis and environmental protection, people's demand for engines "clean alternative fuel" developed, is the urgent need to resolve key issues (Sukumar,2005). Therefore, speeding up the development of internal combustion engines "clean alternative fuel", is the key to solving the problem. As a green and renewable source, bio-diesel have received wide attention around the world. Bio-diesel has some outstanding advantages among various alternative fuels(Alireza,2016; Ng,2015).

However, Domestic and foreign researchers have discovered that when bio-diesel use as fuel, extracted directly from plant, there exist many problems. Ryan believes that its existing two problems(Luka,2016; Bahamin, 2015), firstly, the combustion characteristics of fuel, such as misfire, poor cold start and ignition delay. Secondly, the incomplete combustion of fuels, that is carbon deposits and fuel nozzle blockage, oil dilution and metamorphic. Spray characteristics of change will affect the mixture in the cylinder of internal combustion engines, as well as the combustion process, that have a deep influence on engine power, economy and emissions.

Biodiesel produced from the year in the 1980 of the 20th century. Although its history is not very long, because of its superior environmental protection and good reproducibility, it gets a lot of national attention. United States, Germany, France, India and Japan and other countries have set up a specialized agency, conducting a study on production and application of biodiesel. Those countries provide a series of preferential measures to actively encourage and promote the development and application of biodiesel in the biodiesel industry norms and terms of use policies(Avinash,2015).

United States was among the first to study biodiesel. At present, the United States has more than half of the States, Such as Washington, California, Missouri, and Ohio and New Jersey, using soya bean oil-vinegar in order to facilitate the application of bio-diesel on state government buses or trucks. Biodiesel is mostly used in Europe, sharing 5%of the oil products market (Najafi, 2016). In biodiesel production and utilization, and Germany developed firstly in the EU leader. At present, the biodiesel is provided in 1500 gas stations in Germany, and its retail price is lower than regular diesel and biodiesel. The using standard of biodiesel in France is adding 5% biodiesel to the Petro-diesel. France CIRAD group carried out a test of 100,000 km bio-diesel combustion on the Renault (Sanjid,2014), and results showed that the biodiesel could be used in car engines. Daimler Chrysler Mercedes added biodiesel to the c-type of Benz, driving around 5900km in India, and results showed that vehicle engines and all the parts were not a problem. Ejim and others(Zhang,2014; Paresh, 2016) from University of Alberta in Canada had a research on the effect of biodiesel
surface tension and viscosity on the atomization, Slovenia Breda (Mosarof, 2015) analyzed the biodiesel-diesel blended fuel injection process using numerical simulation method under different conditions. 

Chicago carried out a test of 20% and 40% biodiesel mixed with diesel respectively on a single cylinder engine in order to make a research on biodiesel combustion and emissions performance. Scholl and Sorenson and others used Soybean biodiesel in direct injection diesel engine combustion, and experimental results showed changing the nozzles had large effect on the engine power and the influence of heating rate, and HC and CO emissions was reduced with NOx no significant change. Schumacher and Borgelt, who applied different blending ratios of biodiesel fuel to heavy duty diesel engine, and biodiesel blending ratios were 20%, 10% and 40% respectively. Experimental results showed that with bio-diesel blending ratio increasing, HC, CO and carbon emissions reduced with NOx emissions increasing. C.S. Lee and S.W. Park and others conducted a research and analysis of the spray and combustion process for biodiesel blended fuel in a common rail diesel engine. The results showed that with biodiesel blending ratios increasing injection rate, mean drop diameter, atomization was relatively weak due to the high viscosity and surface tension of biodiesel. In Japan, it is very popular to use waste food oil as raw material to produce biodiesel. Japan government has approved biodiesel fuel provided by the gas station as a commodity and its biodiesel price is lower than petroleum diesel. To sum up, the questions of current biodiesel research are as follows. Firstly, the physical and chemical properties of biodiesel are not comprehensive enough. Secondly, the effect of various components of blended biodiesel on performance and emissions of diesel engine were not detailed enough. Thirdly, spray mechanism of biodiesel and combustion process were partly studied, focusing on macro factors. Fourthly, biodiesel has the combustion characteristics of misfire, poor cold starting and ignition delay. Fifthly, there is incomplete combustion, such as carbon deposits and fuel nozzle blockage, oil dilution and spoilages and so on.

Under this background, aiming at the different physical and chemical properties of diesel or biodiesel, we have carried out a sequence of experiment on spray characteristics of mixed fuels with different blending ratios, to have a further study on the effects of biodiesel on engine performance and optimize the biological diesel engine performance. Under the test conditions it is systematically revealed that the complex of bio-fuel injection spray atomization characteristics and mechanism on macro and micro aspect to make up for the lack of field research in the study of biodiesel spray micro issue at home and abroad.

2. EXPERIMENTAL METHODS

2.1. Experimental Instruments and Principles

Malvern laser particle analyzer is one of many particle measurement method that most widely used. Spraytech have real-time measurement function, you can analyze and aerosol spray droplet size distribution ejection means, and measure spray particle size large dynamic range (0.1-2000 um) in the distribution of the maximum capture speed up to 10kHz (one measurement every 100 microseconds), fully capturing the spray of dynamic activity (Zhang, 2016; Tinprabath, 2015). The real-time measurement principle of Malvern laser particle analyzer is based on a lot of motion particle multi-source Fraunhofer diffraction of monochromatic light, the optical system is shown in Figure 1.

![Optical system of Malvern Method](image)

Figure 1. Optical system of Malvern Method

When a monochromatic laser beam is irradiated from an equal vertical spray particle beam into a spray field, Fraunhofer diffraction is mono-disperse, that is, it consists of a series of concentric light and dark stripes constitution and the spacing between fringes depends on the diameter of the particle if the particle diameter of the spray field is average. However, the spray particle size is not average in actual, shows poly-dispersit, so it will form a large number of Fraunhofer diffraction fringes concentric aura and each aura fringe spacing corresponds to a set of particles of a diameter. Those fringes concentric aura superimpose together, received by the receiver located at the focal point of the lens by means of Fourier lens. Stripes auea range, the range of particle diameter, depends on the scope of Fourier lens focal length. Check receiver consists of 31 concentric semi-circular photosensitive rings, that Layout from the inside out and whose function is the superposition of concentric interference fringes are sorting and conversion. Each photosensitive ring interference fringes aura
of a particular particle diameter is most sensitive to the certain energy of diffraction fringes, that can measure interference fringes with different particle size distribution of the energy spectrum if combined. Light detection receiver photo-ring electric output to multiple a/d converter, then digital signal transmission to the computer statistical energy spectrum distribution of interference fringes. Computer calculated distribution of particle size distribution and the mean diameter based on energy spectrum, particle size distribution and display the column curve chart timely. Particle size by this methods is under the influence of particle location in spray, which can be used to spray of particle density, extremely high velocity particles can also ensure a high degree of accuracy.

2.2. Experimental Equipment

In order to test bio-diesel fuel in different mixing ratios of spray characteristics and understand the impact of the incorporation of different proportions of bio-diesel spray atomization, we built the experimental equipment, as shown in Figure 2.

![Figure 2. Sketch of experimental equipment](image)

The experimental system consists of tank, hand pump, fuel injector, malvern laser particle analyzer, computer and some related software. Hand pump experiment equipment can provide a 16-22MPa oil pressure, injector for the PB2pintle injector, injection pressure 18MPa. Malvern particle size Analyzer can detect fuel spray particle size distribution, whose result entered into the computer for analysis and processing.

2.3. Experimental Program

This experiment detected the impact on spray quality of bio-diesel and diesel after the incorporation of different proportions of bio-diesel. Relevant physical properties of bio-diesel and diesel are shown in Table 1 (the data is measured when injector pressure is 16MPa and the fuel injected into the atmosphere to measure).

| Table 1. Physical and chemical properties of biodiesel and diesel |
|---------------------------------------------------------------|
| **Biodiesel**       | **diesel**        |
| Density (20°C) kg/m³ | 877.9             | 836             |
| Kinematic viscosity (20°C) mm²/s | 7.146             | 4.81            |
| Open Cup flash point °C | 195               | 64 (Closed up flash point) |
| Cetane             | 47.5              | 55              |
| Sulfur content, %  | 0.0049            | 0.0274          |

Experiments were tested pure bio-diesel (B100), pure diesel (B0), diesel fuel mixed with 10% bio-diesel (B10), diesel fuel mixed with 20% biodiesel (B20), diesel fuel mixed with 50% bio-diesel (B50) these spray characteristics kinds of conditions.

Meanwhile, for a more detailed, comprehensive and accurately understand the impact of bio-diesel spray quality, in spray process of B0, B10, B20 and B50 or B100, we detect spray Sauter diameter (SMD) and cumulative volume distribution using Malvern laser particle analyzer in the distance of 200mm, 300mm, 400mm and 500mm to the fuel injection harness.

In addition, experimental method like using inkjet paper for B0, B10, B20 and B50 or B100 fuel Jet spray angle of the beam was tested.
3. EXPERIMENTAL RESULT

3.1. Spray Angle

In order to compare diesel and bio-diesel nozzle atomization and spray angle difference, B0, B10, B20 and B50 or B100 spray cone angle are measured by spraying white wet method. Measurement is in the vertical distance below the hole for 300mm place a sheet of white paper, and hand pump handle, when it was printed on white fuel injection, spray wet white will be immediately measured the diameter of the wet stains on white paper. Figure 2 diagram of test and the corresponding geometry, spray angle can be get by simple calculation (a is the spray angle in this diagram), numerical results are shown in table 2.

![Spray angle measurement diagram and corresponding geometric relationship](image)

Table 2. Spray angle of the mixed fuel of different mixing ratio

| Fuel   | B0 | B10 | B20 | B50 | B100 |
|--------|----|-----|-----|-----|------|
| Spray angle(°) | 20.1 | 19.8 | 19.2 | 18.5 | 17.2 |

Fuel at high pressure from the nozzle after by airflow disturbance and fragmentation. Physical properties of density and liquid spray characteristics, viscosity and surface tension have a great relationship. As it can be seen from Table 2, as bio-diesel blend ratio increases, the mixed fuel spray cone angle decreases, mainly due to the large motion induced viscosity bio-diesel, usually viscous liquid Effect of atomization quality to make it worse, when the high viscosity of the liquid, the liquid cone beam may become a long straight line, so that bio-diesel larger kinematic viscosity fuel oil droplets resulting in further fragmentation of the more difficult , spray angle becomes smaller, and less volatile bio-diesel also make spray angle becomes small.

3.2. The Sauter Diameter of Atomized Droplet

The average diameter of the spray drop have many statistical evaluation methods, usually statistical arithmetic mean diameter, geometric mean diameter statistics, but the most common is the Sauter mean diameter, referred to as SMD. The principle is that all the fog particles with a uniform diameter sphere with the same surface area and volume to approximate, the ball diameter is the Sauter diameter. Sauter diameter is a very important indicator to evaluate the quality of the fuel spray. Sauter diameter(SMD) is measured in the atmosphere of the B0, B10, B20, B50 and B100 in injector pressure of 18MPa and fuel beam are 200mm, 300mm, 400mm and 500mm. The results are shown in Table 3 and Figure 4.

With the increase of bio-diesel blends, fuel spray Sauter diameter showed a growing trend. Within the nozzle distance from 300mm range, various blends of diesel Sauter diameter smaller than the biological variation in the spray beam distance 300mm after various changes larger than the blend of bio-diesel Sauter diameter. At the same time, a variety of blend ratio of bio-diesel spray with spray beam distance increases, the fuel spray Sauter diameter increasing trend was pure diesel B0 and B10, B20, B50 and B100 pure bio-diesel fuel injection when the beam of 500mm Sauter diameter when compared to 200mm, the rate of increase was 19.2%, 40.1%, 42.4%, 28.8% and 41.9%.

Table 3. Sauter diameter of biodiesel of different blending ratio (μm)

| Measuring distance | 200mm | 300mm | 400mm | 500mm |
|--------------------|-------|-------|-------|-------|
| Hybrid diesel      |       |       |       |       |
| B0                 | 16.7  | 18.88 | 18.91 | 19.91 |
| B10                | 16.34 | 18.05 | 22.57 | 22.9  |
| B20                | 15.79 | 18.74 | 20.54 | 22.48 |
| B50                | 18.14 | 19.51 | 21.9  | 23.36 |
| B100               | 16.85 | 20.03 | 22.54 | 23.92 |
This is mainly because the aerosol just left the nozzle, due to the high injection pressure, speed jet beam generating air resistance in the entrainment effect of the strong, so that part of the droplets atomized. Stabilizing the droplets depends on the surface tension of the liquid, which prevents the minimum energy deformation of surface of the droplets, atomization surface tension equal to the desired increase in the amount multiplied by the surface area of the liquid; Further, the viscosity of the liquid on the size of the atomized droplets also have some impact, the increase in kinematic viscosity will reduce the Reynolds number Re. slow down the development of turbulence, preventing round spray jets or jet fragmentation film, so coarse spray droplet size, droplet collision and bonded into a larger the probability of oil droplets increases, the average diameter of the spray droplets field increases. With the development of the fuel spray beam spray beam power reduced, slowed down, reduced air entrainment. At the same time a part of the fine particle atomization, leaving only part of the fine particles and larger particles continue to move forward and continue to disintegrate into tiny droplets. Meanwhile, the movement of the droplets collide with each other, but also a part of the droplets combine to generate larger droplets. Therefore, the fuel spray jet Sauter diameter with increasing distance from the beam increases with the increasing ratio of the bio-diesel blend, the greater the increase in amplitude Sauter diameter. Description diesel and bio-diesel blends, the increase in the number of large particles of oil droplets in the spray droplets, atomization quality deteriorates.

![Graph](image)

**Figure4.** Sauter diameter of biodiesel of different blending ratio in different measuring distance(µm)

### 3.3. Atomized Droplets Size Distribution

1) Rosin Rammler distribution

Spray droplet size distribution in more in-depth study, and sometimes only listed the average diameter of the droplet distribution function, but also in the distribution curve and then find a few characteristic points were analyzed. These characteristic diameter to investigate some cases the droplet size distribution of great value. In total volume of the droplet size distribution curve, they represent less than the diameter of a droplet of the volume of all droplets of the total percentage of total volume, and the ratio of the subject in the form of symbols marked under which the characteristic diameter is the most commonly used mass median diameter D0.5, indicates that all of the droplets are smaller than the diameter of 50% of the total volume of all droplets. In addition to D0.5, there D0.1, D0.9, D0.632 characteristics diameter (Avinash, 2016; Vu, 2015).

![Graph](image)

**Figure5.** The cumulative volume distribution of B 0 at the beam spray distance of 500mm.  

![Graph](image)

**Figure6.** The cumulative volume distribution of B 10 at the beam spray distance of 500mm.
Average Particle Size Distribution (average scatter, weighted)

| Event | 0.00 | 0.00 | 0.79 | 100.00 | 100.00 | 6.36 | 2.12 | 100.00 | 0.12 |
|-------|------|------|------|--------|--------|------|------|--------|------|
| % V   | 2.36 | 0.00 | 35.14 | 0.10   | 16.77  | 0.00 | 100.00| 0.00   | 0.12 |
| Size (µm) | 1.25 | 0.00 | 6.44  | 99.21  | 100.00 | 0.00 | 0.00  | 0.00  | 0.00 |
| % V < 73.85 | 19.25 | 4.45 | 0.00  | 26.29  | 0.00   | 2.39 | 0.06 | 0.22   | 100.00|
| Size (µm) | 0.02 | 0.57 | 0.54  | 100.00 | 0.00   | 0.00 | 0.00  | 0.00  | 0.00 |
| % V < 10 | 0.44 | 0.73 | 0.56  | 0.49   | 100.00 | 0.00 | 0.00  | 0.00  | 0.00 |
| Size (µm) | 0.00 | 0.00 | 99.31 | 1.14   | 61.88  | 1.11 | 0.25  | -0.29 | 0.00 |
| % V < 100.00 | 0.00 | 2.07 | 9.05  | 0.00   | 100.00 | 0.00 | 2.07  | 9.05  | 0.00 |
| Size (µm) | 0.00 | 0.00 | 93.09 | 3.19   | 3.19   | 78.19| 0.00  | 0.00  | 0.00 |

In addition to spray quality can be used to evaluate this Sauter diameter, the spray field size of various particle size distribution will also be formed and combustion properties of the mixture have a huge impact (Anirudh, 2015; Wan, 2015), and therefore, the spray particle experiments cumulative volume diameter distribution were studied. Figure 2-3 to 2-7 as B0, B10, B20, B50 and B100 biodiesel blend ratio in different beam spray distance of 500mm diameter at the cumulative volume distribution graph.

Experimental results show that the above figure, the cumulative volume of fuel spray from the spray beam beam distribution at 500mm at various biodiesel blend ratio condition. We can see that B0, B10, B20, B50 and B100 of Rosin Rammel diameters 34.67µm, 42.03µm, 37.09µm, 37.21µm and 41.32µm. Uniformity index were 2.03, 1.89, 2.17, 1.93 and 1.97. Thus, it can be seen from the experimental results, increasing the blending ratio of biodiesel with poor quality fuel spray, the cumulative volume was significantly larger particle size distribution curve direction, large particle size increases the number of the fuel spray of droplets. Meanwhile, the droplet size distribution of the highest B20, B10 lowest, B0, B50 and B100 uniformity of size distribution is closer.

2)D0.1 Distribution

According to the results, you can get B0, B10, B20, B50 and B100 in 200mm, 300mm, 400mm and cumulative volume distribution data spaces corresponding to 500mm. Table 4 and Figure10 is D0.1 corresponding data.

| Measuring Distance Hybrid diesel | 200mm | 300mm | 400mm | 500mm |
|---------------------------------|-------|-------|-------|-------|
| B0                              | 12.16 | 13.28 | 13.78 | 12.73 |
| B10                             | 16.34 | 18.05 | 22.57 | 22.9  |
| B20                             | 10.14 | 12.95 | 14.02 | 15.51 |
| B50                             | 12     | 13.66 | 14.3  | 15.01 |
| B100                            | 10.99 | 10.03 | 13.99 | 14.58 |

As it can be seen from the experimental results, B0, B10, B20, B50 and B100 other than blending jet fuel bundle with increasing distance in 200mm, 300mm, 400mm and 500mm at D0.1 value increases, but small differences. Description spray beam has little effect on the distance D0.1 values. Wherein B0, B20, B50 and B100 in jet fuel bundles each value relatively close distance of D0.1, illustrate several fuel when a cumulative volume of 10% corresponding to the characteristic diameter similar, but compared to B10 fuel and more than a
few, D0.1 value significantly larger, indicating mixed with 10% biodiesel in diesel, the mixed fuel atomization deteriorates, reducing the number of fine droplets.

![Figure 10. D0.1 values of biodiesel of different blending ratio at different measuring distance](image)

**3) D0.5 distribution**

B0, B10, B20, B50 and B100 200mm, 300mm, 400mm and 500mm premises D0.5 corresponding data corresponding in Table 5 and Figure 11.

As can be seen from the experimental results, B0, B10, B20, B50 and B100 other than blending jet fuel bundle with increasing distance, and significantly increased in 200mm, 300mm, 400mm and 500mmat D0.5 value. Description with increasing distance from the spray beam, increasing the number of fuel droplets large particle size. Wherein the spray beam at various distances, D0.5 maximum value of B100, B50, B10, D0.5 value B20 reduced in turn, D0.5 pure diesel B0 minimum value. This indicates that pure diesel B0 cumulative volume of the droplet size of less than 50% are relatively small, while blended with biodiesel fuel, B20 value than the B100, B50 and B10 to be small.

B0, B10, B20, B50 and B100 200mm, 300mm, 400mm and 500mm premises D0.5 corresponding data corresponding in Table 5 and Figure 11.

![Table 5. D0.5 value of biodiesel of different blending ratio (μm)](image)

| Measuring Distance | Hybrid diesel | 200 mm | 300 mm | 400 mm | 500 mm |
|-------------------|---------------|--------|--------|--------|--------|
| B0                | 23.65         | 26.57  | 26.17  | 29.23  |
| B10               | 22.99         | 25.88  | 31.3   | 33.9   |
| B20               | 22.84         | 26.64  | 29.2   | 31.41  |
| B50               | 26.98         | 26.8   | 31.75  | 34.3   |
| B100              | 25.93         | 30.49  | 34.11  | 34.48  |

![Figure 11. D0.5 values of biodiesel of different blending ratio at different measuring distance](image)

**4) D0.9 Distribution**
Table 6. D0.9 value of biodiesel of different blending ratio (μm)

| Measuring distance Hybrid Diesel | 200mm | 300mm | 400mm | 500mm |
|---------------------------------|-------|-------|-------|-------|
| B0                              | 41.68 | 47.61 | 45.28 | 54.16 |
| B10                             | 40.51 | 45.5  | 55.39 | 64.81 |
| B20                             | 43.19 | 47.86 | 52.72 | 55.91 |
| B50                             | 50.43 | 47.87 | 59.44 | 64.14 |
| B100                            | 54.51 | 56.68 | 61.77 | 60.83 |

As can be seen from the experimental results, when the jet beam distance of 200mm, B0, B10 and B20 D0.9 value relatively close, are relatively small, while the B50 and B100 of D0.9 larger value. With the change in the distance the spray beam, B0, B20 and B100 D0.9 value of the spray beam with a small change in the distance increases, and B50 and B10 D0.9 value of the spray beam with a large variation in the distance increases. 500mm at the small D0.9 value B0 and B20, and B10, B50 and B100 of D0.9 larger value. Through the above analysis showed that the incorporation of bio-diesel in diesel fuel, D0.9 value of the fuel spray becomes large. In different blend ratio of bio-diesel blended oils, D0.9 value B20 is relatively small.

Figure 12. D0.9 values of biodiesel of different blending ratio at different measuring distance

5) Different spray beam distance D0.1, D0.5 and D0.9 Change Analysis

D0.1, D0.5 and D0.9 Changes situation of B0, B10, B20, B50 and B100 bio-diesel in a variety of blending ratio at 200mm, 300mm, 400mm and 500mm are shown in Figure 13 to Figure 16.

As can be seen from Figure 13 to 16, various biodiesel blend ratio of D0.1 varies over the entire range of the spray beam is not large, this is mainly due to the volume of statistics only 10%, the proportion of small, so the
difference is small. D0.5 and D0.9 spray over the entire range of the beam changes more obviously, especially D0.9, B20, B10, B50, B100 and B0 compared to vary widely, and in turn increase. For example, in the spray beam at 400mm, B0 value of D0.9 45.28μm, and B100 of D0.9 is 61.77μm, increased 36.4%. Description with increasing bio-diesel blending ratio of the fuel atomization situation deteriorated during the mixing of the fuel spray droplets increase in the number of large particles, small particles decline in the number of oil droplets, spray droplet diameter were all characterized by Big. But in different proportions of bio-diesel blending ratio in the case of B20 relatively good atomization.

4. CONCLUSIONS

By Malvern laser particle size analyzer, the relevant parameters of biodiesel of different blending ratios (B0, B10, B20, B50 and B100) at the respective spray beams 200mm, 300mm, 400mm and 500mm have been detected, and the impact of biodiesel on atomization characteristics has been analyzed.

1) Since the kinematic viscosity of biodiesel is larger than diesel, if biodiesel is added to diesel, the spray angle of the fuel will decrease, and the spray angle of mixed fuel will be declining with increasing biodiesel blending ratio.

2) With the increasing of spray beam distance for the biodiesel of different blending ratio, the Sauter diameter of fuel spray increase gradually. The increased rates of the Sauter diameter of the fuel bundles for the pure diesel B0, B10, B20, B50 and pure biodiesel B100 fuel injection at 500mm compared with 200mm were 19.2%, 40.1%, 42.4%, and 41.9%.

3) In the context of distance from nozzle 300mm, the Sauter diameter of the biodiesel of different blending ratios has been little difference. When the spray beam distance is more than 300mm, the Sauter diameter of the biodiesel of different blending ratios has been significantly greater than the diesel. And for the biodiesel of different blending ratios, the Sauter diameter of B20 has been the smallest.

4) From the cumulative volume distribution curve of fuel injection beam, with increasing of the biodiesel blending ratio the quality of fuel spray has been worse and the cumulative volume distribution curve has been moving toward the larger diameter direction. Besides, the number of large particle droplets in the fuel spray has been increasing and the Rosin Rammler diameter of B10 has been largest. Meanwhile, for the uniformity of droplet size distribution, B20 has been the highest while B10 has been the lowest and B0, B50 and B100 has been closer.

5) With the increase of the spray beam distance, the gap of Spray characteristics D0.1, D0.5 and D0.9 for the mixed fuel of a variety blending ratio has been widen which indicates that the number of large particle sizes of droplets in fuel has increased. And spray beam distance has little effects on the D0.1 value of the biodiesel of various blending ratios but has large effects on the D0.5 and D0.9 values, especially on D0.9 value. For example, at the spray beam 400mm, the D0.9 value of B0 is 45.28μm while the D0.9 value of B100 is 61.77μm.

6) The D0.1 value of B10 compared with the biodiesel of other various blending ratio fuel was significantly larger. At every position of the spray beam, the D0.5 value of B20 is smaller than that of B100, B50 and B10. It is indicated that the spray atomization situation of B20 is relatively good in the biodiesel of different blending ratio.

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