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Effect of lubricant oil additive on size distribution, morphology, and nanostructure of diesel particulate matter

Yuesen Wang, Xingyu Liang *, Gequn Shu, Xiangxiang Wang, Xiuxiu Sun, Changwen Liu

State Key Laboratory of Engines, Tianjin University, Tianjin 300072, PR China

HIGHLIGHTS

- Pour point depressant (PPD) has great impact on particulate matters.
- The number of nanoparticles increases sharply after PPD is added.
- Ambiguous boundaries can be found when the PPD additive was added.
- PPD changes the size distribution into bimodal logarithmic.
- Three nanostructure parameters are changed greatly by PPD.

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ABSTRACT

Effects of lubricant oil additive on the characterization of particles from a four-cylinder turbocharged diesel engine were investigated. Neat diesel and blended fuel containing oil pour point depressant (PPD) additive were chosen as the test fuels. Effects of different fuels on size distribution, morphology, and nanostructure of the diesel particles were studied. Transmission electron microscopy (TEM) and high resolution TEM (HRTEM) were employed to study the morphology and nanostructure parameters. Particle size distribution was measured by fast particulate spectrometer (DMS 500). According to the experimental results, distribution of the primary particles size of the two fuels conforms to Gaussian distribution, whereas the mean diameter of blended fuel is larger than that of neat diesel at 1200 rpm, which is contrarily smaller at 2400 rpm. Besides, fractal dimension (D_f) of aggregates increases close to 2 ($D_f = 1.991$), indicating that the structure became compacter with adding PPD. As to the nanostructure parameters of the blended fuel particles, the layer fringe length decreases from 1.191 nm to 1.064 nm, while both the separation distance and tortuosity increase. The changes in the nanostructure parameters indicate that the particles are more ordered and compressed with burning pure diesel. Results of blended fuel from DMS show that more particles, particularly nucleation mode particles, were discharged. In addition, its size distribution become bimodal logarithmic at 2400 rpm. All these results can provide new information of the effects of oil PPD additive on the formation and characterization of diesel particles.

1. Introduction

Diesel engines are inherently more efficient than gasoline engines. Thus, they are widely used in both stationary and mobile applications, especially those that require high power output [1]. As cited in previous works, more than 4 million barrels of diesel are burnt per day in the U.S [2], about 53% of new cars are equipped with diesel engines, and this ratio is increasing every year [3]. Although often resulting in smaller amounts of carbon monoxide and hydrocarbon emissions compared with gasoline engines, diesel engines emit significantly higher fine and ultrafine particulate matter (PM) [4]. These particles in the atmosphere can adversely affect the climate via photochemical reactions, and increasing evidence has associated diesel particles with several health problems [5–7].

On the other hand, diesel engines is downsizing design or pursuing higher power density (HPD); achieving this objective will increase the in-cylinder pressure, temperature, and friction of diesel engines. Hence, high-grade modern lubricant oil is needed to meet the HPD design.

Compared with traditional oil, several kinds of additives are added into modern oil to improve its quality and to optimize its physical and chemical properties [8]. Pour point depressant (PPD)

* Corresponding author. Tel./fax: +86 22 2789 1285.
E-mail address: lxy@tju.edu.cn (X. Liang).

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Nomenclature

Abbreviation

ATDC	after top dead center
BMEP	brake mean effective pressure
BTDC	before top dead center
CA	crank angle
DPF	diesel particle filter
HPD	high power density
PM	particulate matter
PPD	pour point depressant
ppm	parts per million
rpm	revolution per minute
UHC	unburned hydrocarbons
TEM	transmission electron microscopy
HRTEM	high resolution TEM

Symbols

A_a	projected area of aggregates (nm^2)
A_p	projected area of particle (nm^2)
D_f	fractal dimension of aggregate
d_p	primary particle diameter (nm)
D_s	separation distance of layers (nm)
L	maximum projected length (nm)
L_a	fringe length of crystal (nm)
T_f	tortuosity of fringe
wt%	weight percent

additive is a type of organic compound, which can optimize the flow performance at low temperatures, optimize the pumping performance, and make transportation of oil more convenient, is one of the widely used additives [9,10]. Both in traditional and modern engine, oil consumption is inevitable, and consumption in cylinder dominates among the several ways [11,12]. So the additive added in is consumed along with the lubricant oil, which may contribute to PM emissions.

To date, much research works have been done for reducing of diesel particle emissions. In these studies, factors of the fuel quality [13], alternative fuels [14,15], fuel additives [16], combustion mode and injection parameters [17–19], after treatment system [20,21] and oil consumption [11,12,22–24] were taken into consideration. However, few studies focus on the influence of oil additive on emission of diesel particles.

A kind of Polyolefins PPD, mainly contains Poly alpha olefins, was chosen in this study. Included in the analysis are the morphology, nanostructure, and size distribution of diesel PMs. Following our previous studies [25,26], 0.5 wt% PPD additive is dosed into diesel as the blended fuel. Given the minor effect of this percentage of PPD on in-cylinder pressure and combustion, it can be supposed that it is the real working environment of combustion chamber. Fast particulate spectrometer (DMS 500, CAMBUSTION) system was used to study number concentration and size distribution; thermophoretic system was used for in-depth characterization analysis by TEM technique. Therefore, the diameter, fractal dimension, and nanostructure parameters can be investigated.

2. Experimental

2.1. Engine, fuel, oil and PPD additive

A four-cylinder direct injection diesel engine was used in this study; the details of its parameters are shown in Table 1. To make the results reproducible, the quality or property parameters of the fuel, lubricant, and PPD used in the experiment were also provided (see Tables 2 and 3). Given the limited conditions, the diesel fuel used in this study is not ultra-low sulfur diesel. The engine was run on an ET2K engine dynamometer manufactured by Renault. Engine data were recorded and stored by EMS2020 system.

Blended fuel was made by adding PPD additive to neat diesel using a dropper to ensure the accuracy; the electronic balance has an accuracy of ±0.01 g. Then the blended fuel was stirred so as to make sure that the blended fuel is homogenously mixed. For current tests, two different engine speeds of 1200 and 2400 rpm under the same engine load (100 Nm, BMEP of 3.49 bar) were considered.

After the engine was started and fully warmed up, it is necessary for the engine to keep running steadily several minutes prior to the test. Certain amount of new fuel should be burned before the next measurement in order to avoid the influence of previous fuel. For all tests, particle size distribution measurement was taken thrice to guarantee the reproducibility of the results.

Table 1
Diesel engine specifications.

Items	Specifications
Model	YN 4100QB
Bore × Stroke (mm)	100 × 115
Compression ratio	17.5:1
Rated power (KW)	80 at 3200 rpm
Max torque (Nm)	310 at 2000–2200 rpm
Nozzle number × Diameter (mm)	6 × 0.24
Injection pressure (MPa)	24.5 ± 0.49
Injection start time (°CA)	14 (BTDC)
Injection end time (°CA)	4 (ATDC)

2.2. Particle sampling systems and data process

Corresponding to the final analysis objectives, particles were collected by different systems. The scheme of the experimental setup is shown in Fig. 1, including the engine, fuel supply system, control system, and the sampling systems.

The main system used to measure the mass and size distribution of PM in this research is the DMS 500. DMS 500 can measure particles with sizes ranging from 5 nm to 2.5 μm; the particles sampled are classified by electrical mobility and then induced into different channels. Additional details about this system, including its working principle, time before sampling, duration of sampling, and control of dilution, are provided in [25]. The key point is that the dilution gas should be compressed high purity air (99.999%). The integrated software equipped with the DMS 500 system can process the collected data spontaneously, and results can be obtained immediately after the measurement.

Table 2
Property of diesel fuel.

Items	Specifications
Cetane index	46.1
Sulfur content (ppm)	350
Density (g/cm^3)	0.839 at 15 °C
Kinematic viscosity (mm^2/s)	2.41 at 40 °C
Aromatic content (wt%)	21.6