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Effect of lubricating oil additive package on the characterization of diesel particles

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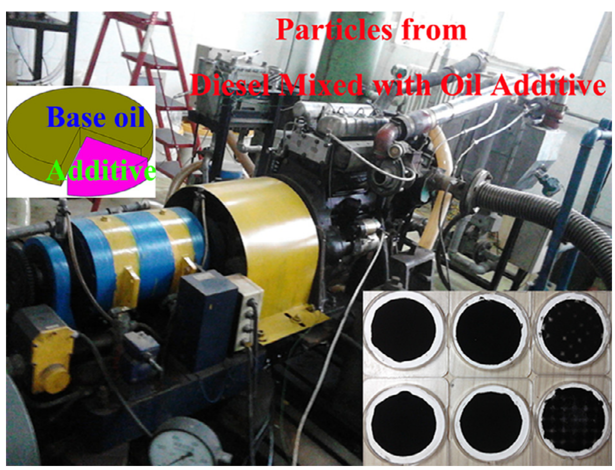
HIGHLIGHTS

- Oil additive package influences the formation and emission of diesel particles.
- Oil additive-derived particles show looser structure compare with normal particles.
- Oil additive package low the graphite degree of diesel particles.
- More ash and volatile fraction were found in oil additive-derived particles.

GRAPHICAL ABSTRACT

Modern lubricating oil is a kind of synthetic product of base oil and additive package. Oil additive package is used to improve the comprehensive quality of oil. However, few research works focus on its influence on emissions, especially the diesel particle emissions. In this study, oil additive package was dosed into pure diesel, and burned along with the diesel. This is to simulate the real condition that oil was consumed in chamber through several resources like blowby from piston ring. Morphology, nanostructure, and composition of diesel particles were analyzed in this study.



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ABSTRACT

In this study, the effects of lubricating oil additive diesel fuel on the diesel engine emission particles characterizations, such as size distribution, morphology, nanostructure and composition was investigated on a light-duty diesel engine. Fast particle spectrum analysis was used for the determination of size distribution, and transmission electric microscopy (TEM) technique for the investigation of morphology of particles. On the other hand, the element carbon fraction can be obtained through thermogravimetric analysis (TGA). Compared with the emission particles from burning pure diesel fuel, the emission particles from burning lubricating oil additive diesel fuel have lower fractal dimension. Measurement results of the nanostructure parameters show that emission particles from burning oil additive dosed fuel have lower graphite structure than those from burning pure diesel fuel. TGA results indicate that more volatile and ash fraction were contained in the particles when oil additive was mixed into diesel. In conclusion, the oil additive may increase the nucleation mode particles and ash component. Therefore, the enhanced

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performance of diesel particulate filter (DPF) system may be required. Thus, the usage of oil additive should be optimized by considering the tradeoff between oil quality and particle emissions contribution.

Nomenclature

BMEP	brake mean effective pressure
DPF	diesel particulate filter
PM	particulate matter
rpm	revolution per minute
TEM	transmission electron microscopy
HRTEM	high resolution TEM
TGA	thermogravimetric analysis

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

1. Introduction

Lower particulate matter (PM) emission level has been the key factor that influences design and development direction of diesel engines except for the requirement of high power density, since the diesel engine emits particles with diameter smaller than 2.5 μm (PM 2.5) and also some content of PM 0.1 [1]. Fine and ultra-fine particles pollute the atmospheric environment via involving in the chemical reactions by large specific surface area and, change the climate or air quality. At the same time, some epidemiologic studies confirmed that nanoparticles that belong to ultra-fine particles bring negative and irreversible health effects on human respiratory system [2,3]. Therefore, it is necessary to understand the characterization, composition and property of diesel particles for reduction of particle emission and development of after treatment system.

Many studies have been done on particles reduction under the drive of stricter emission regulations [4,5]. To date, the studies are related to the design of fuel injection system [6], combustion mode [7], fuel quality and alternative fuel [8,9], and development of after treatment system [10]. To investigate characterizations of particles, thermogravimetric analysis (TGA), transmission electron microscopy (TEM) techniques have been used in many studies [11]. Besides, some studies turned their focus on the lubricating oil, and found that oil age and volatile fraction affect the hydrocarbon and particle emissions. As concluded by Cartellieri and Tritthart [12], the oil contributes to about 90% SOF in diesel particles, the similar result was also drawn by Lapuerta et al. [13]. Also the element tracing method has been used to study the contribution of oil carbon to PM emission [14], results showed that about 4 ± 1% of PM emissions were oil-derived. Froelund and Yilmaz [15] has done much work about the contribution of oil to PM emission, and concluded that there may be 37% of particle mass from oil. From the work done by Kahandawala et al. [16] in a shock tube, the major formation mechanism of PM is dry soot adsorbing oil as SOF. To eliminate the interference of carbon from fuel, Miller et al. [17] did the experiment on a hydrogen fueled engine, and Wei et al. [18] accomplished their study by fueling dimethyl ether. Even though the research works have non-uniform value of the contribution of oil to PM emission, the oil does influence the engine emissions.

Lubricating oil is essential to engines with its functions of lubricating, cooling, sealing, and rust resistance, etc. According to research works, oil is responsible for reducing friction loss and fuel economy [19]. Modern lubricating oil has much difference from traditional oil for better performance. Several kinds of additives, like pour point depressant, antiwear agent and anti-oxidation additive, are integrated and added into oil base stock [20,21]. The primary objective of the synthetic additives is to improve the comprehensive quality of oil and reduce the fuel consumption. However, how does the oil additive package influence the emission via combustion along with oil and fuel is not well understood yet with the limited related works [21–24].

The objective of this study is to find out the influence of lubricating oil additive package on the formation, characterization and composition of diesel particles. As suggested by Ref. [25], proportion of oil additive package was dosed and mixed into neat diesel and burned in the chamber. Particles were collected through thermophoretic system and quartzes filter for TEM test and TGA, respectively. Morphology, nanostructure and composition of particles were analyzed and compared with particles from neat diesel fuel. With the results of this study, we could understand how the oil additive package influences the particle emissions, which will be helpful to meet the emission regulations, to improve the regeneration performance and to prolong the change interval of DPF system.

2. Experimental section

2.1. Test engine, fuel, oil and additive package

All of the experiments in this study were conducted on YN4100QB, a 4-cylinder direct injection diesel engine, which is equipped with turbocharged system and adopted on the light trucks widely, detail information is provided in Table 1. During the study, the engine was operated at low (1200 rpm) and medium (2400 rpm) speeds under medium load (100 N m, BMEP of 3.49 bar), the operation data was controlled and recorded simultaneously. The reason why these two load conditions were chosen is

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 (N m)	310 at 2000–2200 rpm