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Property of Transient Particle Number Emissions from Diesel Engines with Biodiesel Fuel for Mechanical Engineering

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ABSTRACT

Particle number emissions from a light-duty vehicle diesel engine during transient state operating conditions were studied. Test fuels were petroleum diesel, pure Jatropha biodiesel, B20 and B50 biodiesel blend fuels. The results show the number of nucleation mode particles from the engine increases when using petroleum diesel during the transient operating condition (Increasing torque at constant speeds). The number of accumulation mode particles increases at the initial stage of the transient process and then descends with increasing torque. The total particle number increases continuously with torque during the transient operating condition, and accumulation mode particles play an important role in the beginning, and nucleation mode particles dominate the later part of the transient operating condition. Dynamic characteristics of particle number using lower biodiesel blend during the transient process is similar to that of petroleum diesel, whereas higher biodiesel blends show distinct differences, and the total particle number and nucleation mode particle number using B50 and pure biodiesel fuels are obviously larger than pure diesel from beginning to end, while the accumulation mode particle number keeps smaller. For the pure biodiesel fuel, the nucleation mode particle number rapidly ascends until the end of the transient process, and accumulation mode particle number continuously descends.

KEYWORDS: *Diesel engine; Emission; Particle number; Transient process; Biodiese*

I. INTRODUCTION

In the past decades, diesel engines experienced a rapid evolution, which leads their share in the field of increasing vehicle industry. However, the significant amount of exhaust particle emissions from diesel engines should be noticeable. Traditionally, many researchers have focused on the engine's steady-state performance and emissions [1-4]. Compared with steady-state operating conditions, transient-state operating conditions of vehicle diesel engines are closer to actual vehicle operating conditions. In reality, the majority of vehicle engine's operation involves numerous transient conditions, but only a very small portion of that is true steady-state. The duration time of transient conditions is shorter, and the supply rate of fuel and air varies with engine condition. Air-fuel ratio, thermodynamic state parameters and many parameters of transient conditions are not under ideal states, and combustion and emission characteristics are quite different from steady-state conditions [5-7]. The emission rates for cruise, deceleration and idle three drive segments greatly differentiate from dynamometer studies conducted at steady engine powers [8]. There is growing demanding to study emissions from vehicle engines under transient operations.

Particle number emissions become more and more important. The latest Europe vehicle emissions legislation (Euro 5) has been implemented. It specifies a limit on particle number emissions over the New European Drive Cycle (NEDC) test, to complement a revised particulate mass limit. Particle number emissions have become a hot topic [9-13]. Meanwhile, many kinds of literature have presented that particle emissions are harmful to human health and the environment. They can penetrate deeply into the human respiratory tract and many other vital organs such as brain or heart [14]. Besides, particles demonstrated mutagenicity and carcinogenicity in biologic studies [15- 16]. Thereby, the motivation is aroused to investigate particle number emitted by a diesel engine under transient operating conditions.

Nowadays, biodiesel, as a kind of promising renewable fuels, is receiving increasing attention with decreasing fossil oil reserves [17-19]. Biodiesel has lots of advantages over conventional fuel diesel. They can reduce exhaust particle mass and gaseous pollutants such as THC and CO [20-23]. As an alternative fuel, biodiesel can be also used neat or blends with petroleum diesel. Many publications have shown that when using low blend ratio biodiesel, the conventional diesel engine generally does not require any modification. Even high blends biodiesel still can be used in many diesel engines with little or no modification [24]. Overview current researches about exhaust particle emissions from engines with diesel/biodiesel blends, considerable attentions have been drawn to steady-state particle mass or particle number emission, has been yet rarely reported transient particle number emission. Thus, the studies of particle number emissions from a vehicle diesel engine fueled with diesel, biodiesel blend fuels and pure biodiesel at typical transient

operating conditions (Increasing torque at constant speeds) were performed in this work.

II. EXPERIMENTAL SECTION

A. Test Engine

The engine used in this study is a light-duty, direct injection, four-cylinder, four-stroke, turbocharged and intercooled diesel engine with the high-pressure common-rail fuel system. It has a 3.3L displacement, with a rated power output of 79 kW at 3200 rpm and a peak torque output of 275 N·m at 2000 rpm.

B. Fuel Properties

The biodiesel fuel is obtained and converted from Jatropha seed in China. Firstly, Jatropha oil was obtained from Jatropha seeds. Then the biodiesel is made through a chemical process called transesterification whereby the glycerin is separated from the Jatropha oil. The process leaves behind two products - Jatropha oil methyl ester (the chemical name for biodiesel,) and glycerin (a valuable byproduct usually sold to be used in soaps and other products). The base diesel fuel is the common petroleum diesel fuel used in China. Important physical and chemical properties of the petroleum diesel and biodiesel fuels are listed in Table 1. The biodiesel has a higher cetane number, a high density and flash point, and lower sulfur content compared to the petroleum diesel, and contains no aromatics. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. In order to understand effects of biodiesel blend ratio on transient particle emissions of diesel engines in details, four kinds of fuels, including the standard China on-road petroleum diesel fuel, 20%, and 50% v/v biodiesel blends with the diesel fuel, and the pure biodiesel fuel (B0, B20, B50 and B100 fuels) were tested in this study.

C. Test Equipment

The test engine was coupled with an electric dynamometer, and a PUMA transient testbed automation system by AVL was used for running and controlling the test engine. Different transient engine conditions could be set and realized by using the PUMA automation system.

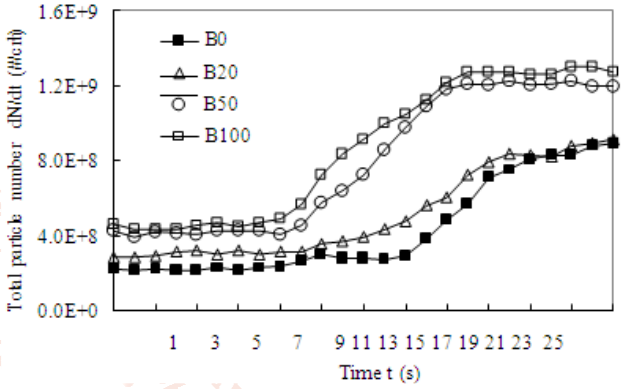
Particle number and size distribution in the engine exhaust were measures by the Engine Exhaust Particle Sizer (EEPS) by TSI Inc. The EEPS is based on the development of the electric aerosol spectrometer and measures particle size from 5.6 to 560 nm with a sizing resolution of 32 channels. The EEPS has rapid measuring speed and gets particle size distribution at a frequency of 10 Hz, which is an ideal instrument for measuring engine particle number and size distribution during transient engine conditions.

D. Experimental Procedure

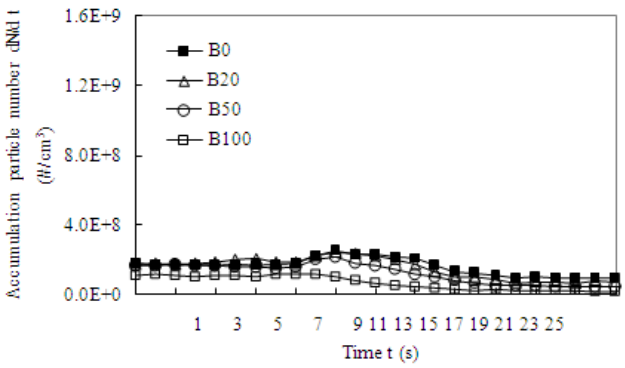
Engine tests were performed without any modification to the engine fuel and air supply systems. The fuels were tested in the following sequence: diesel (B0), B20, B50 and B100 fuels. In the actual operating conditions of vehicle engines, sharp load changes at constant speeds are one of the usual transient operating conditions. Thus, three typical operating conditions in the study were torque from 28 N•m to 206 N•m at one constant speed (2000 rpm (the speed at maximum torque)). The transient operating condition is named A condition.

III. RESULTS AND DISCUSSION

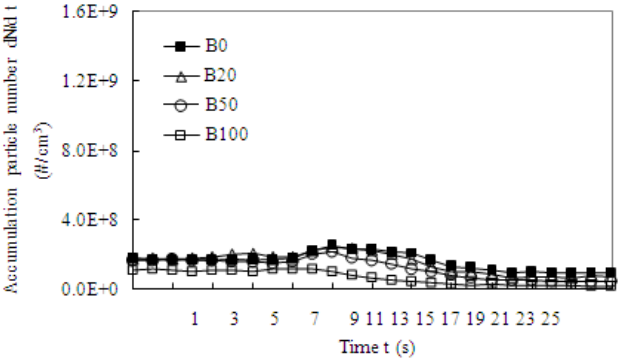
The exhaust particle number of the transient process was given chronologically in Fig.1. Each entire operating condition lasted 60 seconds. Analysis of experimental data shows exhaust particle number remains constant level after the 25th second. So, the beginning 25 seconds were adopted in the study. The total particle number, nucleation mode particle number and accumulation mode particle number were given at the condition A with four fuels respectively. At the 7th second approximately, the torque of engine began to change, and it was the start time of the transient process. In the study, two aspects will be discussed and analyzed in the following: (1) The exhaust particle numbers of the engine with pure diesel fuel at transient conditions; (2) The effects of biodiesel on exhaust particle numbers of the diesel engine at transient conditions.



A. Total particle number



B. Nucleation mode particle number



C. Accumulation mode particle number

Figure1. Diesel particle number emissions of A transient operating conditions, 2000rpm

A. Transient particle number emissions of pure diesel fuel

As shown in Fig.1, the engine was at steady state at the beginning 7 seconds of the A condition (2000rpm). During the beginning 7 seconds, the parameters, which include total particle number, nucleation mode particle number and accumulation mode particle number, change very small. With the subsequent transient process, the parameters did not shift instantly at the very beginning 7th second. In fact, they are a little delayed because of the delaying response of sampling equipment of the dilution system. Though the EEPS has rapid measuring speed, the response of the whole system is still a little delayed.

From Fig.1, the trend of total particle number and nucleation mode particle number for pure diesel fuel is ascending, both featuring slowly first and rapidly later. While the accumulation mode particle number increases first, then continuously decreases. The nucleation mode particle number dominates the trend of total particle number variation. As the experiment goes on, the total particle number, nucleation mode particle number and accumulation mode particle number gradually tent to steady-state. The particle number emissions of the engine at the A transient operating condition are discussed in detail as follows.

(1) Accumulation mode particle number. The transient process features with sharp torque increase at constant engine speed. In the initial period after the 7th second, the fuel injection quantity was increased in the cylinder, but the intake air supply was delayed due to the behavior of the exhaust turbocharging system. So, transient air-fuel ratio in-cylinder is decreased, resulting in the local lack of oxygen and bad combustion. Then, the soot emission ascends and the accumulation mode particle number increases, in which soot accounts for a large percentage. With torque further increasing, the exhaust energy is added, and the air supply delaying of the turbocharging system is improved, and the combustion becomes better, and the soot emission declines, leading to the reduction of accumulation mode particle number.

(2) Nucleation mode particle number. In the initial period after the 7th second, nucleation mode particle number did not change obviously. With the further increase of torque, the added fuel injection quantity lead to more heavy unburned HC emissions, which promote the nucleation mode particle formation. During the transient process, the nucleation mode particle number is far higher than the accumulation mode particle number.

(3) Total particle number. The total particle number is the comprehensive result of both nucleation mode and accumulation mode particles. In the initial period of torque increasing under the A transient operating condition, the accumulation mode number emissions contributed more to the total particle number emissions, while in the latter time, nucleation mode particles have a larger percentage and dominate the total particle number.

B. Effects of biodiesel on transient particle number

Particle number emissions for B20, B50 blends and pure biodiesel fuels are different from the pure diesel fuel (Seen in Fig.1). Compared with pure biodiesel or blending biodiesel fuels, the total particle number from the engine with pure diesel remains the smallest during the A transient process. The total particle number and nucleation mode particle number for B20 fuel are slightly higher than diesel fuel, while accumulation mode particle number is slightly smaller. Dynamic characteristics of total particle number, nucleation mode particle number, and accumulation mode particle number for B20 fuel are similar to the pure diesel fuel. The total particle number emissions for B50 fuel are apparently higher than that for B20 fuel, and accumulation mode particle number is somewhat lower, but the nucleation mode particle number is dramatically higher. When it comes to the total particle number and nucleation mode particle number for pure biodiesel, they remain constantly larger than B50 fuel. The results indicate that nucleation mode particles account for the majority of total particles in this condition. It is observed that over the entire A transient process, there are no large differences between B50 and pure biodiesel in the total particle number, and the nucleation mode particles of the two fuels are significantly more than accumulation mode particles respectively. The transient performance of nucleation mode particles of the two fuels is similar, as well as accumulation mode particles. Thereby, high blend ratio biodiesel will cause a remarkable increase in total particle number concentrations, especially the number of nucleation mode particles.

IV. CONCLUSIONS

Particle number emissions from a light-duty vehicle diesel engine during transient state operating conditions were studied.

(1) The results show the number of nucleation mode particles from the engine increases when using petroleum diesel during the transient operating condition (Increasing torque at constant speeds). The number of accumulation mode particles increases at the initial stage of the transient process and then descends with increasing torque. The total particle number increases continuously with torque during the transient operating condition, and accumulation mode particles play an important role in the beginning, and nucleation mode particles dominate the later part of the transient operating condition.

(2) Dynamic characteristics of particle number using lower biodiesel blend during the transient process is similar to that of petroleum diesel, whereas higher biodiesel blends show distinct differences, and the total particle number and nucleation mode particle number using B50 and pure biodiesel fuels are obviously larger than pure diesel from beginning to end, while the accumulation mode particle number keeps smaller. For the pure biodiesel fuel, the nucleation mode particle number rapidly ascends until the end of the transient process, and accumulation mode particle number continuously descends.

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