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The effect of dynamic operating conditions on nano-particle emissions from a light-duty diesel engine applicable to prime and auxiliary machines on marine vessels

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ABSTRACT: *This study presents the nano-sized particle emission characteristics from a small turbocharged common rail diesel engine applicable to prime and auxiliary machines on marine vessels. The experiments were conducted under dynamic engine operating conditions, such as steady-state, cold start, and transient conditions. The particle number and size distributions were analyzed with a high resolution PM analyzer. The diesel oxidation catalyst (DOC) had an insignificant effect on the reduction in particle number, but particle number emissions were drastically reduced by 3 to 4 orders of magnitude downstream of the diesel particulate filter (DPF) at various steady conditions. Under high speed and load conditions, the particle filtering efficiency was decreased by the partial combustion of trapped particles inside the DPF because of the high exhaust temperature caused by the increased particle number concentration. Retarded fuel injection timing and higher EGR rates led to increased particle number emissions. As the temperature inside the DPF increased from 25 °C to 300 °C, the peak particle number level was reduced by 70% compared to cold start conditions. High levels of nucleation mode particle generation were found in the deceleration phases during the transient tests.*

KEY WORDS: Cold start; DPF; Prime and auxiliary machine; Nano-sized PM; Transient.

INTRODUCTION

Early diesel engines in heavy-duty trucks, diesel-powered buses, and light-duty vehicles produced black smoke that caused poor visibility and unpleasant odors. Markle and Brown (1996) and Zervas et al. (2005) found that advanced technologies could treat and reduce the emissions from on-road and off-road vehicles. Hagena et al. (2006) found that the improvements in engine technologies included engine design, quality of combustion, fuel spray angle, and atomization of fuel by high pressure injection as well as advanced technologies for fuel formulations and after-treatment.

However, although clean diesel engines with state-of-the-art technologies produce no visible emissions, they emit small particles that form fine dust in the atmospheric and have adverse health effects. Epidemiological studies (Dockery et al., 1993; Lee et al., 2009; Ostro, 1984) have found that small particles can have a negative effect on human health. In addition, many studies have found that particles in the atmosphere are an important factor in mortality and morbidity rates.

Current particulate matter (PM) standards for diesel passenger vehicles regulate particle emissions in terms of the total mass of PM emitted per kilometer traveled. Andersson (2001; 2004) found that these regulations are an effective way to control larger-sized particle emissions because the finer particles contribute little to the total mass of PM emissions. The UN-ECE

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GRPE Particle Measurement Program (PMP) was developed recently to improve these emission problems. In addition, new particle number emission regulations will be enforced for diesel passenger vehicles (Andersson et al., 2007; Regulations, 2008).

In the marine boundary layer, the international convention for the prevention of pollution from ships (MARPOL) of the International Maritime Organization (IMO) and the "Blue Sky Series Program" of the U.S. EPA (Environmental Protection Agency) emission regulations for marine vessels with diesel engines are based on gaseous pollutants and mass-based PM. In view of future standards, Kasper et al. (2007) and Dolphin and Melcer (2008) stressed that it is important to characterize nano-sized particle emissions.

The operating principles of four-stroke diesel engines for vehicles and marine applications are similar. Light-duty turbo-charged common rail diesel engines have been used on commercial and naval ships as small power plants. However, the operating conditions in the two applications are different. Before transitioning to cruising navigation, marine diesel engines go through a transient condition; however, the transition portion of the cruise is small compared to the length of the cruise. In the case of road vehicles, transient drive conditions, such as rapid starts and stops with transient acceleration and deceleration, are dominant. In addition, Welaya et al. (2011) showed that power plants powered by natural gas, diesel, or gasoline fuels can be used as the main propulsion engines and for electric power generation in small ocean-going vessels. In this context, high power diesel engines with bores smaller than 100 mm were selected to be analyzed in detail.

The purpose of the work presented here was to analyze the particle number and size distribution characteristics of a turbocharged diesel engine with a catalyzed particulate filter under dynamic engine operating conditions such as engine speed and load, cold start, transient, and engine parameters. This type of engine is applicable to main and auxiliary engines on small boats or naval vessels.

EXPERIMENTAL SECTION

Test engine

Fig. 1 shows a schematic diagram of a light-duty turbocharged diesel engine that was used to analyze the nano-sized particle characteristics during steady operation and transient conditions. The diesel engine is a single overhead camshaft (SOHC), in-line, four cylinder, 2.5 *liter* turbocharged common rail direct injection (CRDI) engine. Fuel is supplied from the fuel tank to the high pressure pump through the low pressure pump, and the common rail pressure is controlled by the high pressure pump during engine operating conditions. Detailed engine specifications and test fuel properties are given in Table 1 and Table 2, respectively.

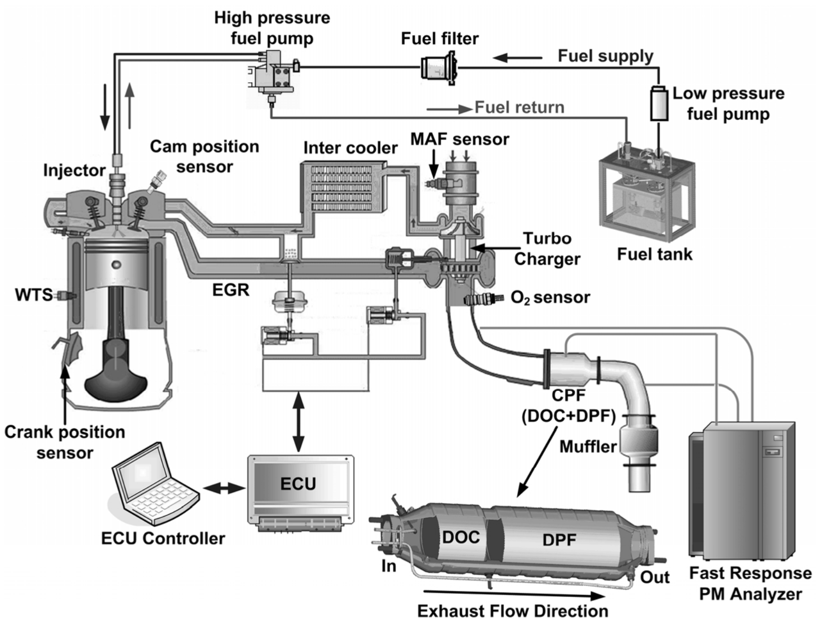

Fig. 1 Schematic diagram of engine experimental system.