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Characterization of Engine Particle Emission Size Distribution by SMPS

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Abstract

Size distribution of particulate matters (PMs) emitted from a diesel vehicle were investigated by using a Scanning Mobility Particle Sizer (SMPS). The single and agglomerated particle sizes of PMs are in the range of 10-60 nm and 60-130 nm, respectively. The maximum single and agglomerated particle numbers are approximately 20-40 nm and 90-110 nm. At the engine warm-up idle condition, the number of single particle is quite high and then gradually decreased with time. Finally, the single particle number is nearly constant after an hour of the engine operates in idle condition. This is an interesting result of particles emission which should be researched in more details to discover the useful information for better understanding and future designs of modern Internal Combustion Engines and Diesel Particulate Filter configurations.

***Keywords**:* Diesel Engine, Particulate Matter, SMPS, Electrostatic Classifier

1. Introduction

Among internal combustion engines (ICE), diesel engines have the highest thermal efficiency for a given output power. However, particulate matters (PMs) must be removed from the exhaust gas emitted from diesel engines to protect the environment and human health. Therefore, regulation of vehicle emissions has become increasingly strict.

The composition of PMs from a diesel engine may vary widely depending on the operating conditions and fuel composition. PM is traditionally divided into three main fractions: solid fraction (SOL) and soluble organic fraction (SOF). The SOL of diesel PMs is composed primarily of elemental carbon, sometimes referred to as inorganic carbon. This carbon, not chemically bound with other elements, is the finely dispersed carbon black or soot substance responsible for black smoke emission. Hydrocarbons (HCs) adsorbed on the surface of the carbon particles are present in the form of fine droplets from the SOF of diesel particulates. At times, this fraction is also referred to as the volatile organic fraction (VOF). The SOF fraction contains most of the polycyclic aromatic HCs (PAHs). PAHs are aromatic HCs with two or more benzene rings joined in various forms that are more or less clustered. The water, unburned HC, carbon and ash regions are verified for oxidation reaction by Thermogravimatric Analysis (TGA) [1–11].

Particle emissions size and structure is very complicate and difficult to measure the exact value because of very small size. Size distribution and nanostructures of soot primary particles have been characterized using scanning electron microscope (SEM) and transmission electron microscopy (TEM) to understand them in detail. The mean diameter of the single primary and agglomerated particles is usually in the range of ultrafine particle (30-60 nm) and fine particle (100-300 nm), respectively [12-16].

The present research objective is to characterize diesel vehicle PM size distribution by using a Scanning Mobility Particle Sizer (SMPS). The results could be compared to the previous research which successfully report PM size distribution by using SEM and TEM images. The result would be successfully described as the useful information of biodiesel PM nanostructures for better understanding and future design of DPF configuration for diesel engines.

2. Methodology

A conventional diesel fuel in Graz, Austria as shown in Table 1 was used in the present research. The lower heating value (LHV) of diesel fuel is 42,482 J/g. Carbon, hydrogen and oxygen contents are 85.6, 13.4 and 0.5 percent, respectively. Diesel PM was emitted from a diesel van as shown in Table 2. The vehicle engine has displacement of 2,461 cm^3 and a rated output of 75 kW. It is a four cylinders, four strokes and direct injection. The engine was operated by idle condition at neutral position. The PM emitted from engine was characterized by "Particle Emission Test Laboratory", Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology, Graz as shown in Fig. 1.

Table 1 Diesel Fuel Properties

	Method	Value	Unit
LHV	DIN 51 900-2 mod.	42,482	J/g
Carbon	DIN 51 732	85.6	% (m/m)
Hydrogen	DIN 51 732	13.4	% (m/m)
Oxygen	DIN 51 732 mod.	0.5	% (m/m)

Table 2 Vehicle and Engine Specification

	Method	Unit
Maker	VOLKSWAGEN	-
Trade Name	KASTENWAGEN TDI	-
Vehicle Type	70 T - KASTEN	-
Fuel	Diesel	-
Engine Displacement	2,461	cc
Rated Output	75	kW
After Treatment	Non-DPF	-

Fig. 1 A diesel van particle emissions test laboratory in "Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology.

Fig. 2 Particle size distribution measurement device "Series 3080 Electrostatic Classifiers (Courtesy of www.tsi.com)".

Fig. 3 A Scanning Mobility Particle Sizer (SMPS) for particle size distribution at "Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology.

Exhaust gas emitted from the exhaust pipe of vehicle was introduced into the dilution system and then gas sample was sucked from the dilution system to a Scanning Mobility Particle Sizer (SMPS) for size distribution characterization in the range of 10 nm to 400 nm diameter as shown in Fig.2 and Fig.3. Gas sample was characterized for both during engine warm-up approximately one hour and also after engine warm-up. The sample was characterized every 10 to 20 minutes.

3. Results and Discussion

Figure 4 shows the particle size distribution during engine warm-up condition. The first peak of particle size distribution is approximately 20 nm to 30 nm. This first region is the single particle of PMs. The second peak of particle size distribution is approximately 90 nm to 100 nm. This second region is the agglomerated particle of PMs. It was clearly observed that during engine warm-up, particle number decreased with time for both single and agglomerated zones. It means combustion efficiency of the engine increased with the temperature of engine during warm-up condition. Moreover, much amount number of single particle could be observed at the beginning of warm-up condition and decreased with time. The number of single and agglomerated particle number are in the same range after 40 minutes engine warm-up in idle condition.

Figure 5 shows the particle size distribution during the second hour of testing. It was clearly seen that amount of single and agglomerated particles are nearly constant in 300 and 400 particles per cubic centimeter, respectively.

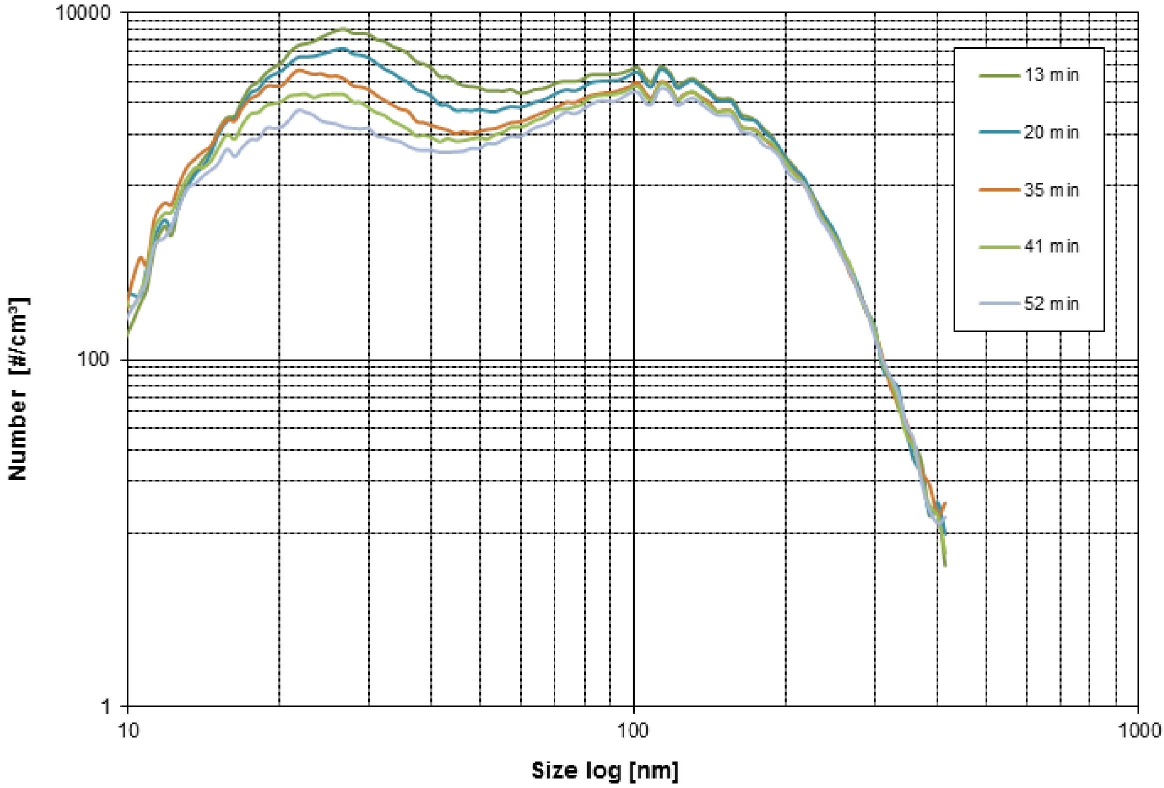

Fig. 4 Particle size distribution of PMs during an hour engine warm-up.

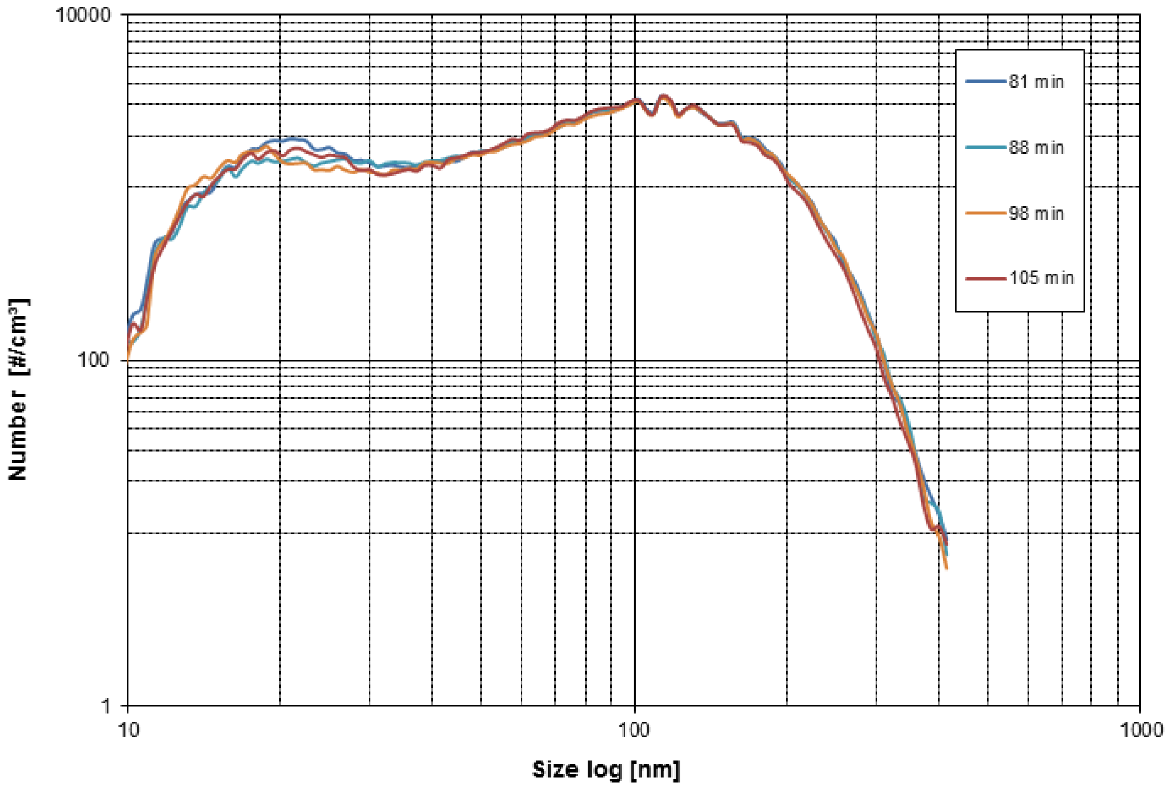

Fig. 5 Particle size distribution of PMs after an hour engine warm-up.

Figure 6 and 7 show Scanning Electron Microscope (SEM) and model images of PMs. Single and agglomerated particle model could be imaged based on the result of SEM images. The particle size range is also acceptable value when compare to the result from Scanning Mobility Particle Sizer (SMPS). However, the small different of size from both type of measurement is depend on the definition of each diameter which should be clearly clarify for high performance DPF design and development.

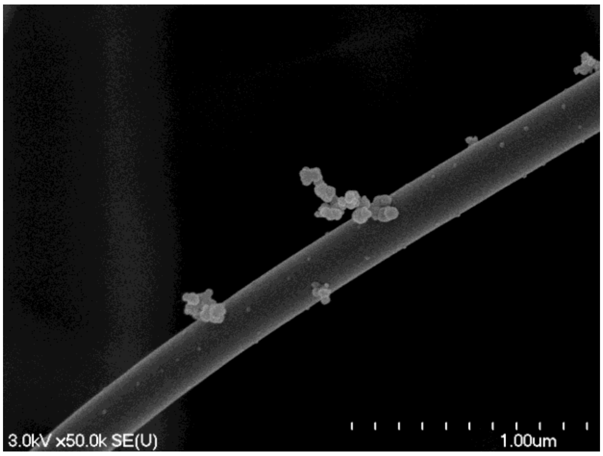

Fig. 6 Scanning Electron Microscope (SEM) images of PMs (Courtesy of Doctoral Thesis, P.Karin Tokyo Institute of Technology).

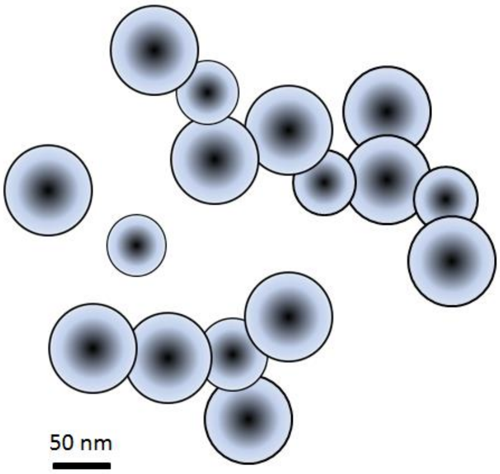

Fig. 7 Model of PMs which consisted of single and agglomerated size.

5. Conclusions

Size distribution of particulate matters (PMs) emitted from a diesel vehicle were successfully investigated by using a Scanning Mobility Particle Sizer (SMPS). The single and agglomerated particle sizes of PMs are in the range of 10-60 nm and 60-130 nm, respectively. Much amount of single and agglomerated particle diameter are in the range of approximately 20-40 nm and 90-110 nm. At the engine warm-up idle condition, the number of single particle is quite high and then gradually decreased with time.

Particle size and structure are agreed with SEM image result from previous research. This is an interesting result of particles emission which should be researched in more details to discover the useful information such as particle weight and charge for future designs of modern Internal Combustion Engines and Particulate Filter configurations.

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