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Characteristics of Nano-Particles Exhausted from Diesel Passenger Vehicle with DPF

Yong-hee Park† · Dae-Yewn Shin*

National Institute of Environmental Research, Korea

**Department of Environmental Engineering, Chosun University, Korea*

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Abstract: The nano-particles are known to influence the environmental protection and human health. The relationships between transient vehicle operation and nano-particle emissions are not well-known, especially for diesel passenger vehicles with DPF(Diesel Particulate Filter). In this study, two diesel passenger vehicles were measured on a chassis dynamometer test bench. The particulate matter (PM) emission of these vehicles was investigated by number and mass measurement. The mass of the total PM was evaluated using the standard gravimetric measurement method, and the total number concentrations were measured on a ECE15+EUDC driving cycle using Condensation Particle Counter (CPC). According to the investigation results, total number concentration was 1.14×10^{11} and mass concentration was 0.71 mg/km. About 99% of total number concentration was emitted during the 0~400s because of engine cold condition. In high temperature and high speed duration, the particulate matter was increased but particle concentration was emitted not yet except initial engine cold condition According to DPF performance deterioration, the particulate matter was emitted 2 times and particle concentration was emitted 32 times. Thus DPF performance deterioration affects particle concentration more than PM.

Keywords: nano-particle, diesel particulate filter, particulate matter, condensation particle counter, driving cycle

Introduction

Recently, Particle emissions such as PM10 and PM2.5 emitted in soil, ocean, traffic and industry are becoming main issue in the air quality point of view.[1-3]

Especially, the emissions of nano-particles from diesel vehicle have received increased attention due to their possible effect on human health. Although diesel engine particulate emissions from new vehicles have decreased due to the application of advanced technologies such as high pressure injection and aftertreatment equipment, particle number has not been controlled. Then the implications of particle emission from vehicles have been studied in a number of large international studies.[4-6] The UNECE-GRPE Particulate Measurement Program (PMP) is the with probably the strongest focus on future regulation of nano-particle emissions form light duty vehicles.[7] Its goal is an amendment to existing type approval legislation to stipulate an extensive reduction of particle emissions form vehicles.

Up to now, the regulations for automotive particle emissions have been based solely on Particulate matter (PM). For regulatory purposes, a new measurement system for particles in vehicle exhaust emissions is being evaluated to complement the existing gravimetric method.

The UNECE-GRPE Particulate Measurement Programme(PMP) started the round-robin test that be tested with same vehicle and measurement system in a major country laboratory for evaluation accuracy, repeatability of recommended test method.

In this study, according to PMP recommendation the number concentration of non-volatile particles is measured in exhaust samples taken from the CVS tunnel, using a thermo-diluter for preconditioning and condensation particle counter (CPC).

We investigated particle emissions of light duty vehicles not only with respect to their total mass but also their particle concentration, also studied relationship between particle emission and transient driving cycle.

Even if the diesel fuel is injected into the cylinder by high-pressure injection, it is not clear

†Corresponding author : National Institute of Environmental Research
Tel. 82-32-560-7620, Fax. 82-32-568-2043
E-mail : nierpark@me.go.kr

that the particulate number concentration decreased. In the point of a view, this work investigate the particle characteristics of nono-particles exhausted from high-pressure diesel vehicle with a diesel particulate filter is applied to reduce the concentration of particulate number.

Methods

Test Vehicle and Methods

Test vehicles were used who diesel passenger vehicles with DPF system. The specification of test vehicles is listed in Table 1.

The chassis dynamometer was used for the measurement of exhaust emission from test vehicle. For the correct measurement of PM, sampling temperature was always controlled within 52°C by dilution. PM emitted from vehicle was collected by the Teflon coated glass fiber filter and weighed by micro balance after conditioning at least 8 hours in the camber which was always controlled within specified temperature and humidity. For the emission measurement of exhaust gases was passed into a constant volume sampler(CVS) where they were diluted with filtered ambient air by HEPA filter. Gas samples were taken from each of the 4 CVS bags. Bag samples were analyzed for regulated emissions(THC, NOx, CO).

The regulated and particle emission from diesel passenger vehicles were tested on the ECE15+EUDC mode which was used for the regulation of vehicle exhaust emission in Korea and Europe. Fig. 1 shows the driving pattern of ECE15+EUDC mode.

Table 1. Specification of test vehicle

Model	Peugeot 407 2.0 Hdi AF
Engine type	RHR
Engine displacement	1997 cc
Max. power	130/4000 (ps/rpm)
Transmission	M6
Aftertreatment equipment	DOC+DPF
Injection type	DI (Max. injection pressure : 1600 bar)

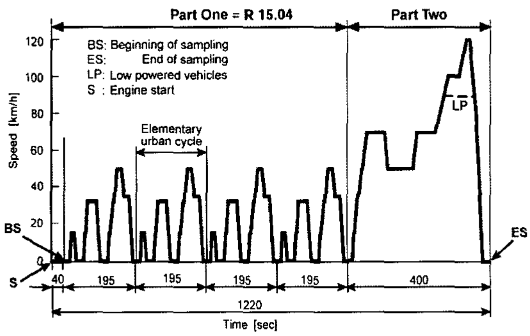

Fig. 1. Driving pattern of ECE15+EUDC mode.

Particle Measurement System

Particle measurement system consists of sample probe, first particle number diluter, evaporation tube, second particle number diluter and CPC, from this system we measured 20 nm-2.5 μm diameter particle. Fig. 2 shows particle measurement system. The particle number measurements were performed by taking the sample out of the dilution tunnel, close to the sample probe for the gravimetric measurement. The samples over 2.5 μm diameter were rejected by cyclone and were immediately diluted in a first particle number diluter. The first particle number diluter shall be specifically designed to dilute particle number concentration and output a dilute sample equal to 150°C ± 5°C to avoid particle nucleation. And by evaporation tube, particles were heated at constant temperature 300°C for removal volatile particles.[8,9]

After cooled dilution by second particle number diluter, samples are sent to CPC. And CPC measures the particle number concentration continuously.

CPC principle to count particles is the below. The usual technique to count particles is to send them "one by one through a laser beam and analyze the light scattered at a certain angle. Each

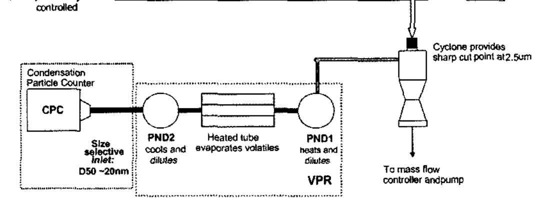

Fig. 2. Schematic diagram of particle measurement system.

particle will produce a detectable light pulse. AS this method works only with particles larger than some 300 nm. The CPC extends the measurement range down to 10 nm or below by condensing a liquid on the particles and thus artificially growing each particle to an optically detectable size. This is accomplished by guiding the nano-particle aerosol through a heated chamber whose walls are clad with butanol drained felt to saturate the chamber with butanol vapour(saturator). In the subsequent condenser the aerosol-butanol mixture undergoes rapid cooling where upon the butanol condenses on all available surfaces, mainly the particles. The latter grow to a diameter of typically 1 μm, almost independent of the size of the initial nano-particle that served as condensation nucleus.

Results and Discussion

Table 2 shows regulated emissions such as CO, HC, NOx and PM in ECE15+EUDC mode driving. All emissions met current emission standard.

Particle Number Concentration

Fig. 3 shows real time transient particle number concentration of ECE15+EUDC mode driving. The black line indicates the speed/time trace for the ECE15+EUDC cycle. Particle emissions were emitted mainly at the engine cold state until early 400s duration. After engine warm up, were emitted not yet and particle below the 10 number were emitted at the higher speed duration until 120 km/h vehicle speed. It showed that particles were reduced by DPF after engine warm up. The highest particle emissions: about 1000 numbers were emitted during early acceleration and at the higher speed condition. This leads to the conclusion that warming of the engine and/or DPF to operating temperature has a significant effect on the rate of particles emitted from a tailpipe. This result is similar to other research carried out by GRPE, ACEA, Lim and Britt.[10-13)]

ECE15+EUDC cycle is made up of 4 times elementary urban cycle and extra urban cycle. Elementary urban cycle is comprise of 195s duration

Table 2. Result of regulated emission

Section	Emission (g/km)			
	CO	HC+NOx	NOx	PM
Result	0.068	0.214	0.221	0.00071
Emission Standard (Euro 4)	0.50	0.30	0.25	0.025

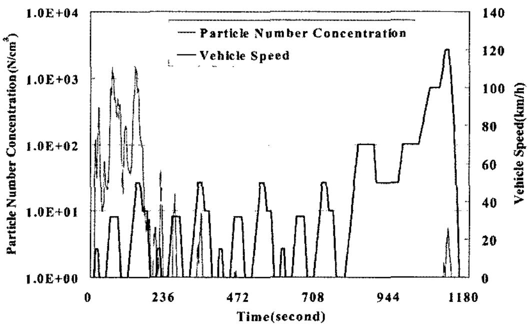

Fig. 3. Real time particle number concentration of duration.

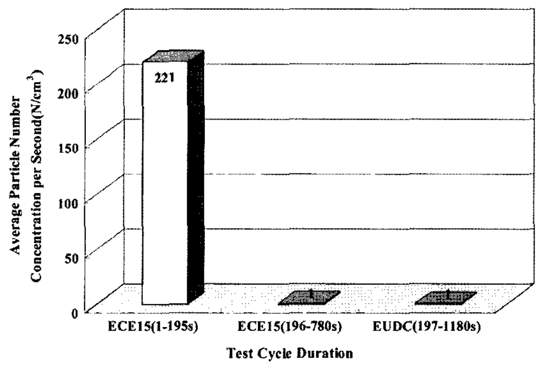

Fig. 4. Average particle number concentration per second according to test cycle.

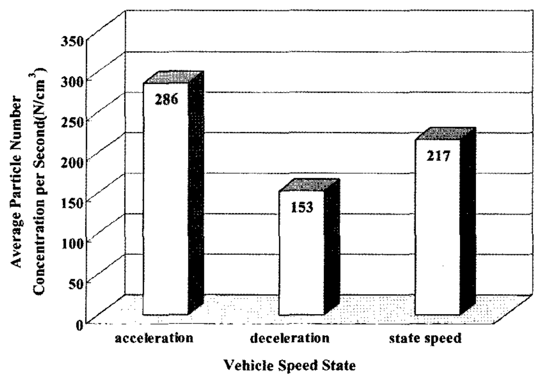

Fig. 5. Average particle number concentration per second according to vehicle speed state.

cycle and extra urban cycle is represent high speed duration. Fig. 4 shows average particle number concentration per second of each duration. at the early elementary urban cycle up to 195s, particle were emitted 221 number. For the cases of ECE15 and EUDC mode, 1 number particle was emitted

Fig. 5 shows particle emission characteristics of speed state that is acceleration, deceleration and state speed. as shown in the figure, particles were emitted highest at the acceleration duration. Average particles were emitted lowest at the deceleration. This is same characteristics to other regulated emissions such as CO, HC, NOx, and PM. This is perhaps not surprising since in each case the emissions result from incomplete combustion.

Comparison of Particle and PM

Fig. 6 shows comparison of total particle number and PM according to test cycle. In the case of ECE15+EUDC mode, the test vehicle emitted the PM of 0.714 mg/km and the particle of 1.14×10^{11} N/km. As divide by each test cycle, the particle and PM emissions had not correlation. Particle emissions were emitted about 99% at the ECE15 cycle. But PM was emitted about 98% at the EUDC cycle. As explained above, it is because particle emissions were emitted mainly at the engine cold condition and at the EUDC cycle that is engine warm up state, were reduced by DPF. Also PM was produced mainly at high load and high speed condition, especially sulfate formation at the high speed condition is derived production of big size particle above 2.5 μm.

Effect of DPF Performance Deterioration on the PM and Particle

As the DPF performance was deteriorated, PM increased about 2 times than vehicle with normal DPF. But particle number concentrations increased about 30 times. Future to meet particle regulation, new DPF development concept will need to be introduced.

Fig. 7 shows real time transient particle number concentration of ECE15+EUDC mode driving. As shown in the figure, the particle number concentration was emitted through the whole duration. Especially at the early engine cold condition and EUDC cycle that high speed and high load condition particle emissions were emitted highly. This is similar to particle characteristics emitted from diesel vehicle without DPF.

Fig. 8 shows average particle number concentration per second of each duration. Compared to Fig.

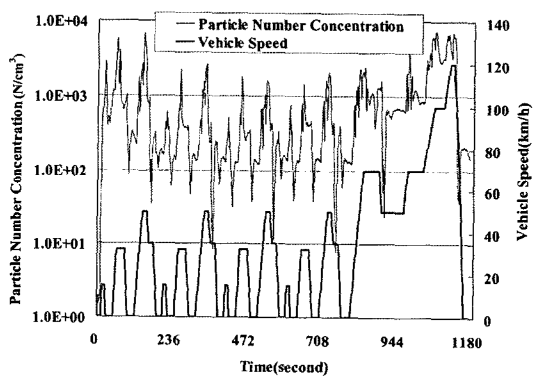

Fig. 7. Real time particle number concentration of ECE15+EUDC mode driving.

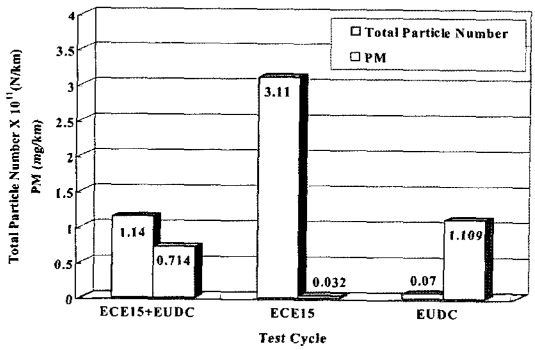

Fig. 6. Comparison of total particle number and PM according to test cycle.

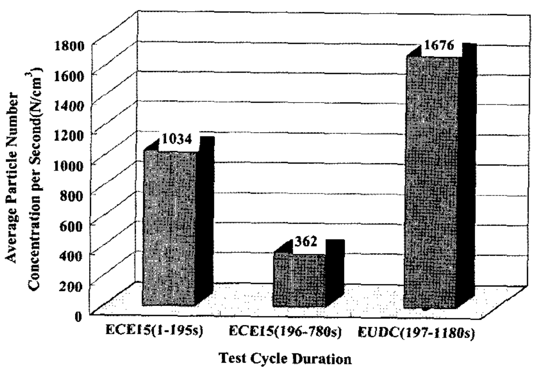

Fig. 8. Average particle number concentration per second according to test cycle duration.

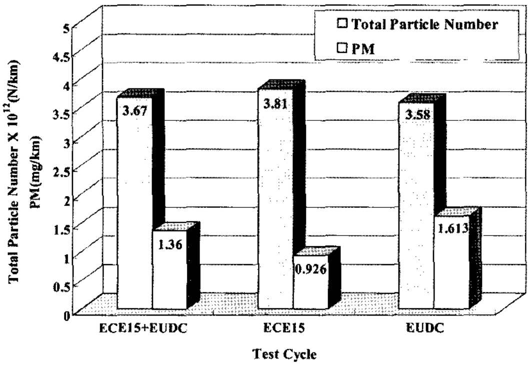

Fig. 9. Comparison of total particle number and PM according to test cycle.

4, Diesel vehicle with normal DPF emitted particle mainly at the early duration until 195s. In the EUDC cycle duration, the particles were emitted highest.

Fig. 9 shows comparison of total particle number and PM according to test cycle. Test vehicle emitted PM 1.36 mg/km and particle 3.67×10^{12} N/km. As divide by each test cycle, particle and PM emission had correlation. Particle emissions and PM were emitted highly at the whole cycle.

Conclusion

The particle number concentration and PM mass concentration have been measured from two diesel passenger vehicles with DPF on the ECE+DUDC driving cycle. The conclusions are as follows:

(1) Particle emissions were emitted mainly at the engine cold start until early 400s duration. After engine warm up, PM emitted not yet and particle below the 10 number were emitted at the higher speed duration until 120 km/h vehicle speed.

(2) The particles were emitted highest at the acceleration duration while the emission of PM were emitted lowest at the deceleration. It is same characteristics to other regulated emission such as CO, HC, NOx, and PM.

(3) Particle emissions were emitted about 99% at the ECE15 cycle. But PM was emitted about 98% at the EUDC cycle. In the case of test vehicle with DPF performance deterioration, generally at the whole duration particle emission was emitted. Especially at the early engine cold condition and EUDC cycle that high speed and high load condition particle emissions were emitted highly. It is similar to particle characteristics emitted from diesel vehicle without DPF.

(4) In the case of test vehicle with DPF performance deterioration, test vehicle emitted 1.36 mg/km of PM and 3.67×10^{12} N/km of particles. As divide by each test cycle, particle and PM emission had correlation. Particle emissions and PM were emitted highly at the whole cycle.

Nomenclature

DPF : Diesel particulate filter
CPC : Condensation particle counter
PM : Particulate matter

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