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Emission characteristics of exhaust gases and nanoparticles from a diesel engine with biodiesel-diesel blended fuel (BD20) †

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Abstract

This experimental study sought to investigate the characteristics of the exhaust emissions, and nanoparticle size distribution of particulate matter (PM) emitted from diesel engines fueled with 20% biodiesel-diesel blended fuel (BD20). The study also investigated the conversion efficiency of the warm-up catalytic converter (WCC). The emission characteristics of HC, CO, NOx and nano-sized PM were also observed according to engine operating conditions with and without exhaust gas recirculation (EGR). The study revealed that the maximum torque achievable with the biodiesel-diesel blended fuel was slightly lower than that achievable with neat diesel fuel at high-load conditions. Smoke was decreased by more than 20% in all 13 modes. While the CO and THC emissions of BD20 slightly decreased, the NOx emission of BD20 increased by 3.7%. Measured using the scanning mobility particle sizer (SMPS), the total number and total mass of the nanoparticles in the size range between 10.6nm and 385nm were reduced by about 10% and 25%, respectively, when going from D100 to BD20. The particle number and mass for both fuels were reduced by about 43% when going from with EGR to without EGR. When EGR was applied in the engine system, the particle number and mass were reduced by 24%, and 16%, respectively, when going from D100 to BD20.

***Keywords*:** Diesel engine; Biodiesel; Catalyst; Exhaust gas recirculation (EGR); Nanoparticle; Scanning mobility particle sizer (SMPS); Warm-up catalytic converter (WCC)

1. Introduction

The diesel engine is the most efficient type of power sources among all types of internal combustion engines. Today, emissions control has become the major driving force in the development of diesel engines, because the use of conventional fossil fuels can cause climate changes, which might lead to ecological disasters in certain areas. In recent years, various methods have been adopted to meet the increasingly stringent exhaust emission standards of vehicles. These methods include high pressure fuel injection systems, multiple fuel injections, exhaust gas recirculation (EGR) [1], diesel particulate filters (DPF) [2], selective catalytic reduction (SCR) [3], and alternative fuels. These diesel technologies were designed to reduce PM and NOx emissions. The diesel engine can use many different alternative fuels such as synthetic diesel fuels [4], biodiesel [5-7], dimethyl ether (DME) [8], alcohols [9], natural gas [10], and hydrogen [11], among others. Many vegetable oils [12] and animal fats [13] have been investigated as diesel fuel substitutes (vegetable or soybean oils are renewable energy sources). Biodiesel is an attractive diesel fuel, because of its renewable character, potential for greenhouse gas emission reduction [14-16], and a generally favorable life cycle [17]. Biodiesel helps reduce CO_2 emission to the atmosphere and the dependence on

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fuel imports. It has no aromatic compounds, practically no sulfur content, and oxygen atoms in the molecule of the fuel, which may reduce the emission of CO, THC, and PM [18-20]. However, biodiesel presents some problems as compared to diesel fuel. These problems include a little higher NOx emission, poor low temperature fuel properties [18-20], and higher production cost [21, 22]. PM is presently regulated in grams per kilometer or grams per kilowatt-hour, but number-based PM regulation is under discussion for introduction in the near future. Nuclei mode particles in the 5-50 nm diameter range, which are one type of particles emitted from engines, account for only 1-20% of the total emitted PM mass, but more than 90% of the total particulate number. The smaller the emitted particle is, the more harmful it is to the body because a smaller particle has a higher surface area, so the easier can the particle infiltrate into the respiratory organs [23, 24]. For these reasons, it has been argued that current regulations on PM emission should shift their focus from particle mass to particle size distribution. As the biodiesel percentage in diesel fuel is increased, the total PM number is decreased and the particle size distribution is displaced towards lower diameter values [16] [18-20]. However, there have been only few studies on the number concentration and size distribution of particles emitted from diesel engines fueled with BD20 for various engine operating conditions. Currently, EGR is widely used to reduce NOx emission from diesel engines [1]. To address the higher NOx emission problem, a biodiesel-fueled diesel engine should adopt EGR [20]. However, there have been no reports on the effects of the biodiesel fueled diesel engine with EGR on the emission characteristics of nanoparticles.

This paper sought to investigate the characteristics of exhaust emission and nanopaticle size distribution, as well as the number concentration of PM from the CRDI diesel engine fueled with biodiesel-diesel blended fuel (BD20) through the ECE R49 test cycle. Moreover, this paper investigated, the conversion efficiencies of a warm-up catalytic converter (WCC) and the effect of EGR on the emissions of HC, CO, NOx and nano-sized PM.

2. Experimental apparatus and methods

2.1 Experimental apparatus

Fig. 1 shows the diagram of the main experimental device used to study the engine performance, emission characteristics and particle size distribution of a CRDI diesel engine using biodiesel-diesel blended fuel. The experimental apparatus consisted of an exhaust gas analyzer system, smoke meter, WCC, SMPS (Scanning mobility particle sizer), and dilutor [20]. WCC was installed in the rear part of the exhaust manifold, while the exhaust pipe leading to the WCC was completely insulated for fast activation. The specifications and dimensions of the test engine are listed in Table 1. Particle size distribution was measured over a diameter range from 10 to 385 nm using SMPS. The particle mass concentration was calculated from the measured size distribution in which the particle density was assumed to be at 1.2 g/cm^3. An eddy current dynamometer (Fuchino, ESF-600) capable of absorbing 440kW was used to measure power performance. An exhaust gas analyzer (Horiba, MEXA-9100DEGR) was used to measure HC, THC, NOx concentrations to within ±1% FS (full scale) accuracy. The Bosch type smoke meter (World Env., ATF-2000) measured the amount of smoke emission [18, 20].

Table 1. Specifications of the test engine.

Items	Specifications
Engine type	4 Stroke, CRDI
Compression ratio	17.1 : 1
Power output (kw/rpm)	112/ 3800
Torque (Nm/rpm)	324/ 2000
Air charging	Turbo-Intercooler
Bore × Stroke (mm)	91 × 96
Displacement (cc)	2497

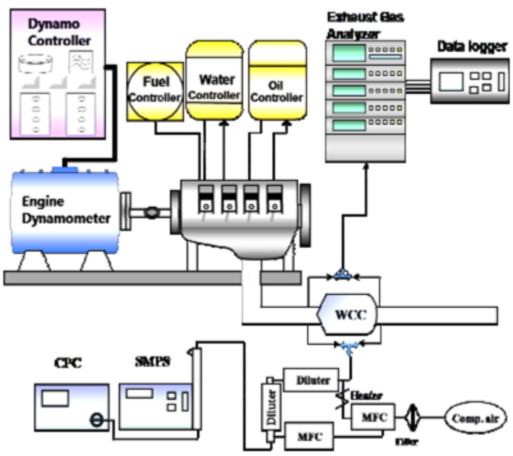


Fig. 1. Diagram of the experimental apparatus.

2.2 Experimental methods

We measured the engine performance, emission characteristics, and particle size distribution of the CRDI diesel engine equipped with WCC using diesel fuel and 20% biodiesel-diesel blended fuel (BD20) produced from soybeans, respectively. The diesel fuel was a Korean ultra-low sulfur diesel fuel (ULSD, lower than 30 ppm sulfur content) referred to as D100. The blended fuel was a ULSD fuel with 20% biodiesel content, referred to as BD20. The 13-mode steady-state test cycle (ECE R49) was adopted for the test (see, Table 2).

Emission characteristics were measured in the exhaust gases upstream and downstream of the catalyst. Smoke was measured at the end of the tailpipe. Part of the exhaust gas and filtered ambient air were mixed at a ratio of 1:132 by using an ejector-type diluter system [18, 20]. Particle concentration strongly depends on dilution conditions [25-26]. The first dilutor in the dilution system preheated the dilution air to about 150±5℃ so that the nucleation and condensation of the volatile components could be prevented. Table 3 shows the specifications of the SMPS and the ejector-type diluter [18, 20]. This test engine operated EGR in modes 1-4. Fuel was injected twice by the pilot and main fuel injections (idle modes; modes 1, 7, 13), maximum torque speed (2100 rpm, modes 2-6) and injected once by the main fuel injection (rated power speed (3800 rpm, modes 8-12)). The WCC of 76 mm in diameter and 0.5l L in volume and the honeycomb type monolithic substrates with cell density of 600 cpsi (cell per square inch) were coated with γ-Al_2O_3 and 2.4 g/L of platinum (Pt).

Table 2. The ECE R49 cycle.

Mode	Engine speed (rpm)	Load rate (%)	Weight factor
1	Idling (750)	-	0.25/3
2	Maximum torque speed	10	0.08
3		25	0.08
4		50	0.08
5		75	0.08
6		100	0.08
7	Idling (750)	-	0.25/3
8	Maximum horsepower speed	100	0.10
9		75	0.02
10		50	0.02
11		25	0.02
12		10	0.02
13	Idling (750)	-	0.25/3

Table 3. Specifications of SMPS and the dilutor.

SMPS (Model : 3080, TSI)	
Description	Specification
Particle size range (nm)	Adjustable : 10 – 1000
Upper concentration limit	10^5
Scanning time (sec)	30 - 300
Dilutor (ejector type, CNU)	
Dilutor	Diluter ratio
1st dilutor (heating to 200℃)	1:12
2nd dilutor (TDR 1:132)	1:11

3. Experimental results and discussion

3.1 Engine performance

When BD20 was used, the maximum torque and rated power decreased by 1.15% and 2.6% of that of D100, respectively. Fig. 2 shows the brake specific fuel consumption (BSFC) curves of the engine for two different fuels in an ECE R49 test cycle. The BSFC ranged 220-400 g/kWh except at the low load condition (2, 12 modes). The BSFC of BD20 in the middle and high load conditions increased slightly. The increased BSFC of the biodiesel-diesel blended fuel was mainly due to the lower calorific value of BD20 than D100. The low heating value (LHV) of BD20 decreased by 3.17% because the energy content of biodiesel was approximately 11% lower than that of D100.

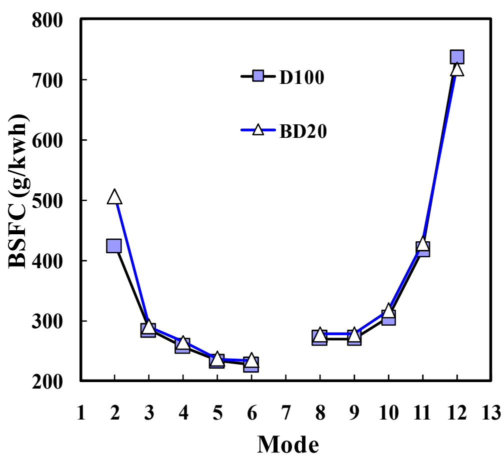


Fig. 2. Break specific fuel consumption of the engine with two kinds of fuel according to the ECE R49 cycle.

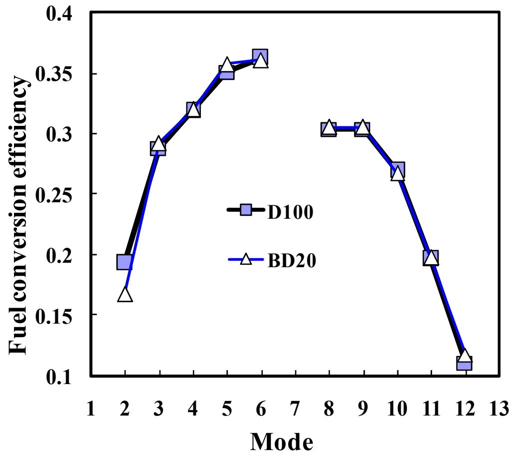


Fig. 3. Fuel conversion efficiencies of the engine with two kinds of fuel according to the ECE R49 cycle.

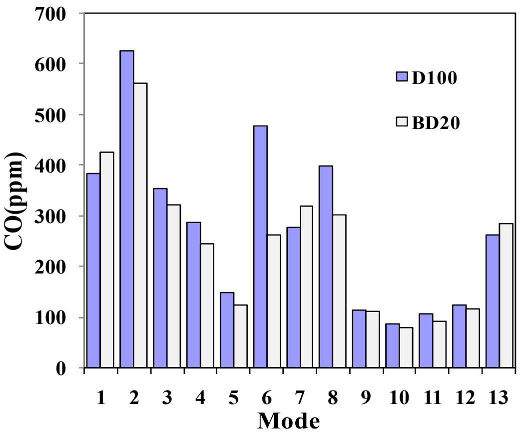


Fig. 4. Effect of BD20 on the CO emissions in the engine.

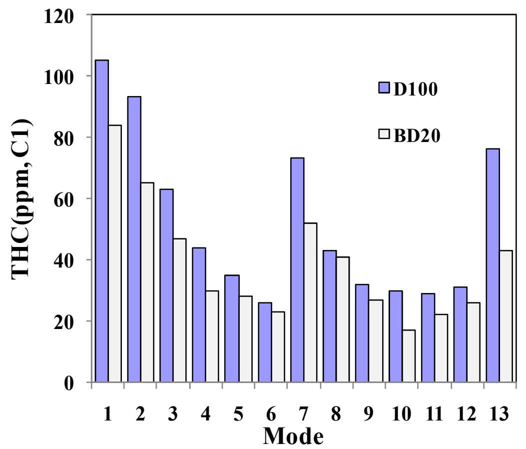


Fig. 5. Effect of BD20 on the THC emissions in the engine.

Fig. 3 shows the fuel conversion efficiency, which was calculated from the BSFC and LHV of the two different fuels. The fuel conversion efficiency of BD20 in the middle and high load conditions was similar or higher than that of D100 because BD20 had a higher reaction activity in the fuel rich zone due to the oxygenate atoms in the molecule of biodiesel at high speed and high load conditions.

3.2 Emission characteristics of diesel and BD20 fuel

Fig. 4 shows the CO emission in each mode for both fuels. The CO concentrations were high at idling (1, 7, 13 modes), low (2 mode) and high load (6, 8 modes) conditions. The CO concentration was considerably reduced with BD20 except at idling, and particularly, the CO emissions of 6 and 8 modes (full load) decreased by 45% and 24% when going from D100 to BD20, respectively. The oxygen content in BD20 enhanced the combustion process in the fuel-rich zone, thereby reducing the formation of CO emission [5]. The average CO emission in all modes of the ECE R49 cycle was decreased by 19.6% when going from D100 to BD20.

Fig. 5 shows the THC emission in each mode for both fuels. THC emission was remarkable in the idling and low load conditions because of the lean mixture and low exhaust gas temperature for both fuels. This could lead to some difficulty in the evaporation and burning of the heaviest hydrocarbons [12]. However, the THC concentration was reduced as the load increased [6]. This was caused by the increased oxygen in diesel fuel. The oxygen in BD20 helped in completing the combustion. The average THC emission in all modes of ECE R49 cycle was reduced by 35% when going from D100 to BD20.

Fig. 6 shows the NOx emission in each mode for both fuels. The NOx concentration in all modes (except idling mode) slightly increased with BD20 [5, 6] [15]. The NOx concentrations in modes 1-4 were low because of the exhaust gas recirculation (EGR) and multi-injection of fuel (pilot and main injection). The NOx concentration of BD20 in the rated power speed range (3800 rpm; 8-12 modes) was higher than that of D100. BD20 promoted NOx formation because biodiesel had some oxygenate content and a bit higher number of cetane as compared to D100. In the ECE R49 cycle, the average NOx concentration increased by 3.7% when going from D100 to BD20.

Fig. 7 shows the Bosch smoke number (BSN) of

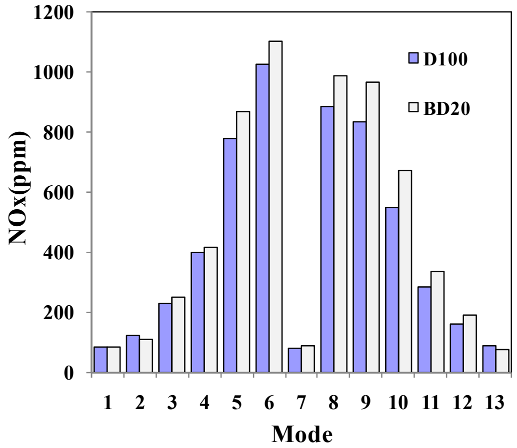


Fig. 6. Effect of BD20 on the NOx emissions in the engine.

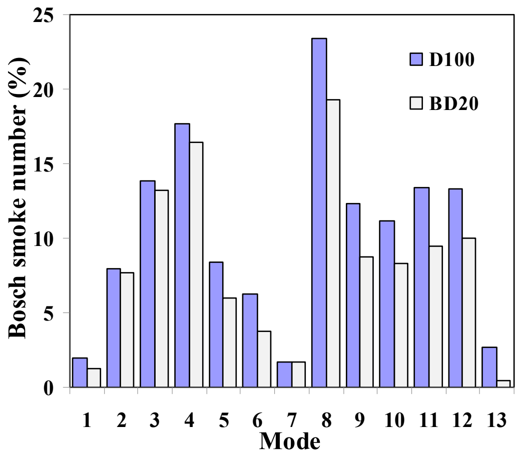


Fig. 7. Effect of BD 20 on the Bosch smoke number in the engine.

the two different fuels for the 13 modes. Smoke emission can be slightly reduced using BD20 [5, 15]. The smoke opacity of D100 increased in the middle- and high-load conditions (modes 4, 8). The high smoke level of D100 (3-4 modes) considerably increased the EGR (operating modes; 3 idles, 2–4) for NOx reduction. Oxygenated fuel contributes to the complete combustion of fuel even in a locally rich zone, so the smoke emission was reduced with BD20. With BD20, smoke emission decreased more in the rated power speed range (single main injection range, modes from 8-12 modes) than in the maximum torque speed range (pilot and main injection range, 2-6 modes). The results revealed that the generation of soot from the fuel-rich regions inside the diesel diffusion flame tended to decrease because of the biodiesel in the fuel.

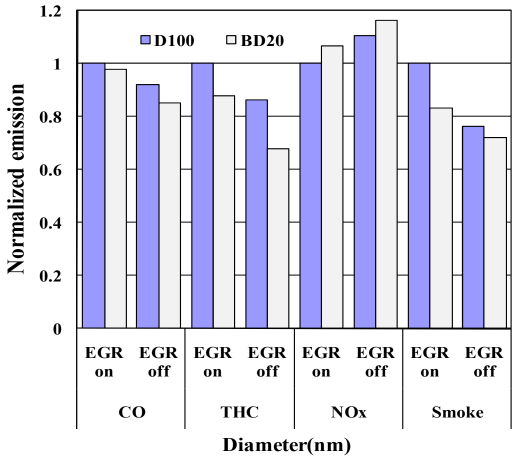


Fig. 8. Effect of EGR on the exhaust emissions in the engine.

Fig. 8 shows the effect of EGR on the exhaust emissions of the two different fuels. Because EGR reduced the oxygen available in the combustion chamber, so this combustion chamber maintained a low temperature, and NOx formation in the combustion chamber was low. For the D100 and BD20 fuels, the NOx emissions reduced by about 10% with application of EGR. However, with the use of EGR, CO, THC, and the smoke emissions increased by about 9-20% because of the incomplete combustion caused by the reduction of the oxygen concentration in the engine combustion chamber. On conditions with or without EGR, BD20 combustion resulted in more effective emissions (HC, CO, smoke) reduction than did D100 combustion. However, NOx emission slightly decreased with EGR. Finally, NOx increment with BD20 fuel could be countervailed to a level similar with that of D100 with EGR, while the smoke was kept low. In this case, the number and size distribution of nanoparticles had to be investigated.

Figs. 9 and 10 show the CO and THC conversion efficiencies of the two different fuels on WCC and the exhaust gas temperature in the upstream of WCC. The CO conversion efficiency on WCC was maintained by about 80% in all modes except mode 1 (lower exhaust gas temperature, approximately 100˚C). Fig. 10 shows that the THC conversion efficiency of the catalyst was maintained by about 40-70% in all modes, except in mode 1. In spite of the high exhaust gas temperature (400-500˚C) in modes 6 (D100), 9, and 10 (BD20), the CO and THC conversion efficiencies were low. This implies that CO and HC emissions may be produced by the catalytic reac-

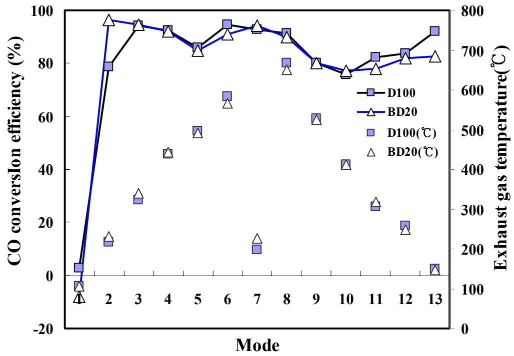


Fig. 9. Comparison of the CO conversion efficiencies and exhaust gas temperatures of WCC between D100 and BD20 fuels.

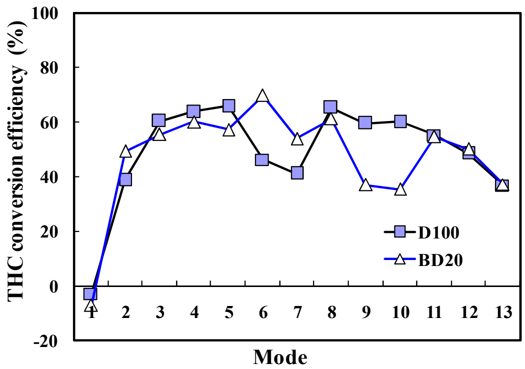
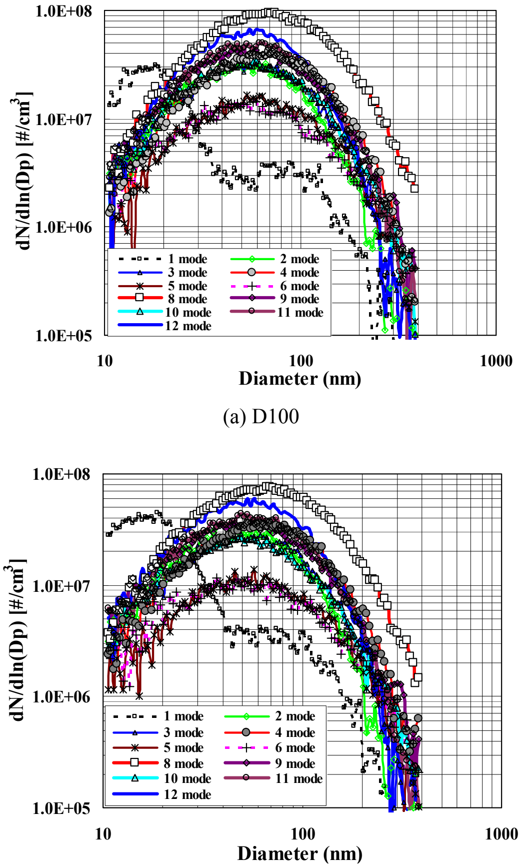


Fig. 10. Comparison of the THC conversion efficiencies of WCC between D100 and BD20 fuels.



(a) D100

(b) BD20

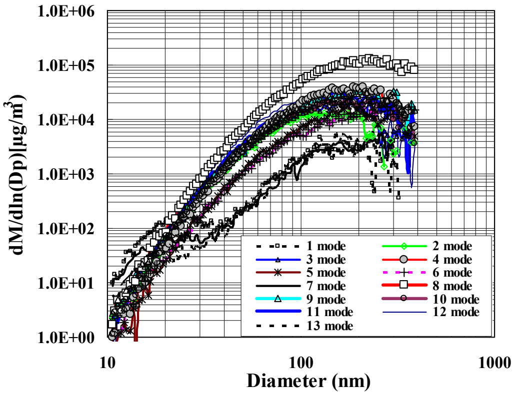
Fig. 11. Particle size distributions and number concentrations with D100 and BD20.

tion of carbon and water vapor. CO and THC conversion efficiencies may also be influenced by a higher space velocity (SV).

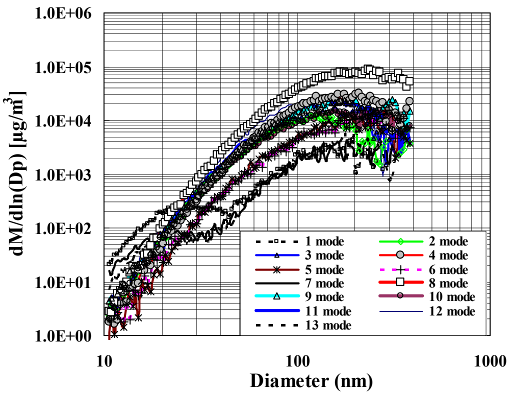
3.3 Particle number and size distribution

Fig. 11 shows the number concentration and size distribution of the particles emitted from the diesel engine in each mode for BD20 and D100. The formation of PM can be influenced by combustion conditions like the fuel injection time and duration, fuel injection pressure, multiple fuel injection, and EGR. For D100, the maximum particle number concentration is 1×10^8 particles in mode 8 (3800 rpm, 100 % load) with a particle diameter ranging from 50 to 70 nm. Based on the figure, the particle number concentration in idle mode 1 is a bi-modal shape with peaks at particle diameters 20 and 60 nm. The high number concentration of particle of 70 nm in diameter in mode 4 has a considerable influence on EGR (EGR operating range; modes 1-4). Owing to PM surface growth and coagulation by the application of EGR, the particle number concentration was increased. The total number of particles from SMPS-data was decreased by about 10% when going from D100 to BD20. This decrease was due to the low soot characteristics of biodiesel.

Fig. 12 shows the mass concentration and the size distribution of the particles emitted from the diesel engine in each mode for BD20 and D100. The peaks of the particle number concentration for the two different fuels appeared in 50 to 70 nm diameter range (see, Fig. 11), but the peaks of the particle mass concentration were in the 200 to 300 nm diameter range. The peak of the particle number concentration in mode 1 was observed near the 20 nm diameter (see, Fig. 11), but the mass of these particles was very low based on the conversion of the peak particle number into mass. With EGR modes, the peak particle mass



(a) D100



(b) BD20

Fig. 12. Particle size distributions and mass concentrations with D100 and BD20.

was evident in the 100 to 200 nm diameter range in mode 4 (2100 rpm, 50 % load). The peak particle mass is presented around the 200 nm diameter in mode 8, which was also corresponded to the highest smoke emission and particle number concentration (see, Fig. 11). The comparison of the particle mass between the two different fuels in mode 8 showed that the particle number concentration was reduced by 20% when going from D100 to BD20 (in Fig. 11), but the particle mass concentration of BD20 was reduced by about 44%. These decreases were due to the oxygen content in biodiesel fuel, which suppressed the formation of soot. Currently, in the case of mass-based PM regulation, biodiesel-diesel blended fuel has the advantage in terms of PM reduction. Nevertheless, systems like the advanced CDPF (catalyzed diesel particulate filter) used for the reduction of PM need to reduce nanoparticles, which are believed to be

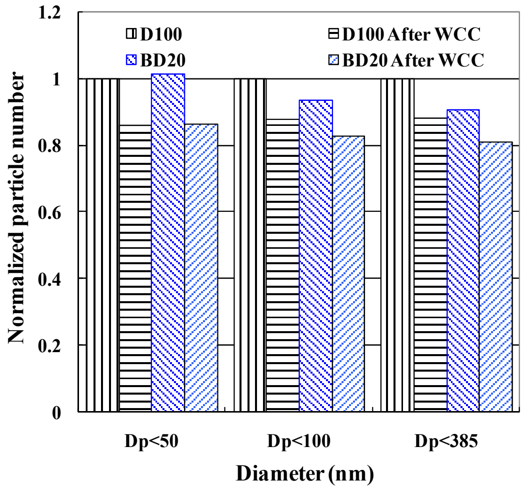
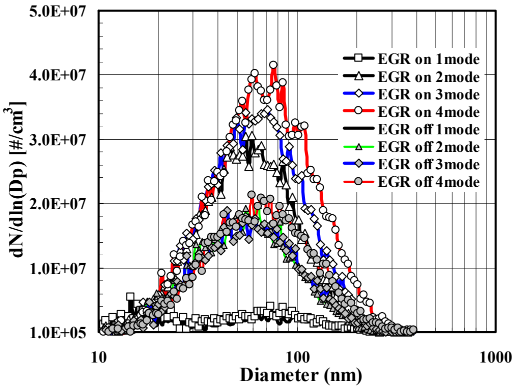


Fig. 13. Normalized particle number concentrations for each size range.

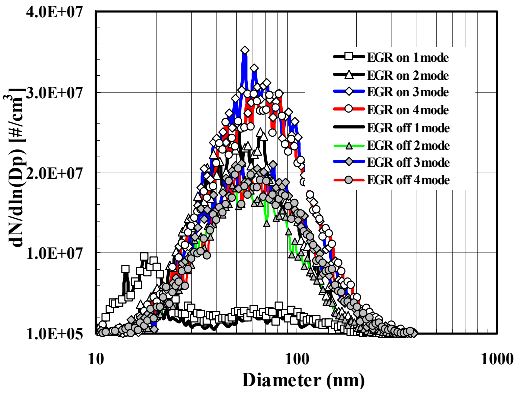
more harmful to human health than larger particles. In the ECE R49 cycle, the total mass of particle calculated from SMPS-data decreased by 25% when going from D100 to BD20.

Fig. 13 shows the normalized particle number concentration as a function of particle size range [26] where the normalized particle number refers to the particle number concentration of BD20 divided by that of D100 without any catalyst in each size range. The particle size ranges are classified according to the following particle sizes: nano-particle (Dp < 50 nm), ultra-fineparticles (Dp < 100 nm), and fineparticles (Dp < 385 nm). The number of particles under 50 nm in the engine-out emission was increased by 1.6% when going from D100 to BD20, but the numbers of particles of 10 < Dp <100 nm and 10 < Dp < 385 nm in size were reduced by about 6.4 % and 9.4 %, respectively. The increase in the number of particles under 50 nm may be due to the increase in soluble organic fraction (SOF) particles. The total particle number downstream of the catalyst was reduced by about 9%, and the reduction rate of the particle number under 50 nm on the catalyst was slightly increased by about 14% because of the high oxidation of the SOF particle [19].

Fig. 14 shows the effect of EGR on the particle size distribution in modes 1-4 for D100 and BD20. EGR is used as the primary control method to reduce NOx emission. However, EGR affects the particle generation from diesel combustion, regardless of the fuel type. The diesel engine fueled with D100 with EGR



(a) D100



(b) BD20

Fig. 14. Effect of EGR on the particle size distribution for D100 and BD20 according to 1-4 modes.

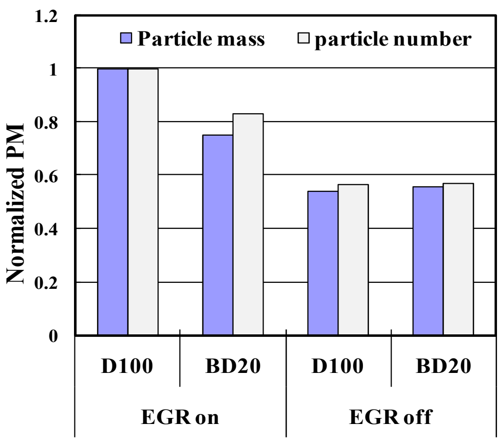


Fig. 15. Effect of EGR on the normalized particle number and mass according to 1-4 modes.

emits two times more number of particles than that without EGR, This is so, because EGR acts as an additional inactivation gas in the intake of air, thereby reducing peak combustion temperatures and NOx formation rates. In addition, EGR affects particle growth including surface growth, coagulation and aggregation. However, with BD20, EGR did not affect the particle numbers significantly. It seems that BD20 combustion was more tolerant to EGR addition than was D100 combustion.

Fig. 15 shows the effect of EGR on the normalized particulate matter (PM) according to 1-4 modes, where the normalized PM defines the particle number or mass concentration of BD20 divided by the particle number or mass concentration of D100 with EGR. The particle number and mass for both BD20 and D100 fuels were reduced by about 43% when going from with EGR to without EGR. When EGR was applied in the engine system, the particle number and mass were reduced by about 24% and, 16%, respectively, when going from D100 to BD20.

4. Conclusions

The emission characteristics and particle size distribution of a CRDI diesel engine equipped with WCC using biodiesel-diesel blended fuel (BD20) were investigated under the ECE R49 cycle. The results of the study are summarized as follows:

(1) The averages of CO, THC and smoke emissions in all modes of the ECE R49 cycle were reduced by about 19.6, 35, and 20 %, respectively, when going from D100 to BD20, but the NOx emission of BD20 increased by 3.7%.

(2) The conversion efficiencies of THC and CO in WCC under D100 and BD20 were about 50% and 80% in the ECE R49 cycle, respectively (except in mode 1).

(3) The total number and calculated total mass of the particles from SMPS-data decreased by about 10% and 25%, respectively, when going from D100 to BD20. However, the number of particles under 50 nm in diameter increased by 1.6%.

(4) The particle number and mass for both BD20 and D100 fuels were reduced by about 43% when going from with EGR to without EGR, and when EGR was applied in the engine system, the particle number and mass were reduced by 24%, 16%, respectively, when going from D100 to BD20.

References

[1] D. S. Kim and C. S. Lee, Improved emission characteristics of HCCI engine by various premixed fuels and cooled EGR, *Fuel* 85, (2006) 695-704.

[2] K. Yuuki, T. Ito, H. Sakamoto, R. Matsubara, S. Hashimotoa, and T. Hamanaka, The effect of SiC properties on the performance of catalyzed diesel particulate filter (CDPF), *SAE paper* No. 2003-01-0383 (2003).

[3] J. F. Kelly, M. Stanciulescu, J.-P. and Charland, Evaluation of amines for the selective catalytic reduction (SCR) of NOx from diesel engine exhaust, *Fuel* 85, (2006) 177-1780.

[4] N. Horvat and F. T. T. Ng, Tertiary polymer recycling: study of polyethylene thermolysis as a first step to synthetic diesel fuel, *Fuel* 78, (1999) 459-470.

[5] K. Y. Ryu and Y. T. Oh, A study on the usability of biodiesel fuel derived from rice bran oil as an alternative fuel for IDI diesel engine, *Journal of Mechanical Science and* Technology 17, (2003), 310-317.

[6] C. D. Rakopoulos, D. T. Hountalas, E. G. Giakoumis and E. C. Andritsakis, Performance and emissions of bus engine using blends of diesel fuel with bio-diesel of sunflower or cottonseed oils derived from Greek feedstock, *Fuel* 87, (2008) 147-157.

[7] S. Y. Im, Y. S. Song and J. I. Ryu, Experimental study of the physical and chemical characteristics of biodiesel blended fuel using ultrasonic energy irradiation, *International Journal of Automotive Technology* 9, (2008) 249-256.

[8] C. H. Hwang, C. E. Lee and S. M. Kum, NOx emission characteristics of dimethyl ether/ Air nonpremixed flames, *Journal of the Korean society of Mechanical Engineers* 31B, (2007), 926-935.

[9] H. Bayraktar, An experimental study on the performance parameters of an experimental CI engine fueled with diesel–methanol–dodecanol blends, *Fuel* 87, (2008) 158-164.

[10] M. J. Moon, S. I. Kim and Y. N. Chun, Hydrogen production from methane under an oxygen- enriched conditions using compression ignition engine, *Journal of Industrial and Engineering Chemistry* 13 (7), (2007) 1117-1121.

[11] Z. Huang, J. Wang, B. Liu, K. Zeng, J. Yu and D. Jiang, Combustion characteristics of a direct-injection engine fueled with natural gas–hydrogen blends under different ignition timings, *Fuel* 86, (2007) 381-387.

[12] M. Lapuerta, O. Armas, R. Ballesteros and J. Fernández, Diesel emissions from biofuels derived from Spanish potential vegetable oils, *Fuel* 84, (2005) 773-780.

[13] A. Kerihuel, M. S. Kumar, J. Bellettre and M. Tazerout, Use of animal fats as CI engine fuel by making stable emulsions with water and methanol, *Fuel* 84, (2005) 1713-1716.

[14] B. C. Choi, C. H. Lee and H. J. Park, Power and emission characteristics of DI diesel engine with a soybean bio-diesel fuel, *Trans.of The Korean Society of Power System Engineering* 6, (2002) 11-16.

[15] Y. T. Oh and S. H. Choi, A study on characteristics of rice bran oil as an alternative fuel in diesel engine (1), *Trans.of The* Korean Society of Automobile Engineer 10, (2006) 15-22.

[16] M. Lapuerta, J. Ferandez and J. R. Agudelo, Diesel particulate emission from used cooking oil biodiesel, *Bioresource Technology* 99, (2008) 731-740.

[17] H. von Blottnitz and M. A. Curran, A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective, *Journal of Cleaner Production* 15, (2007) 607-619.

[18] H. N. Kim, Y. H. Sung, T. J. Kim, B. C. Choi, M. T. Lim and J. J, Suh, Characteristics of exhaust emission and particle size distribution using biofuel blended Diesel fuel in CRDI Diesel engine with CPF, *Trans. of The Korean Society of Power System Engineering* 12, (2008) 5-12.

[19] H. N. Kim, Y. H. Sung, K. S. Jung, B. C. Choi and M. T. Lim, Size distribution and number concentrations of particles from the DOC and CDPF, *Journal of Mechanical Science and Technology* 22, (2008) 1793.

[20] H. N. Kim and B. C. Choi, Effect of ethanol–diesel blend fuels on emission and particle size distribution in a common-rail direct injection diesel engine with warm-up catalytic converter, *Renewable Energy* 33, (2008) 2222-2228.

[21] J. M. Marchetti and A. F. Errazu, Technoeconomics study of supercritical biodiesel production plant, *Energy Conversion and Management* 49**,** (2008) 2160-2164.

[22] Energy for the Present and Future: A World Energy Overview, *Springer Berlin Heidelberg,* 3-34 (2007).

[23] California Energy Commission, Emission reduction technology assessment for diesel backup gen-

erators in california, P500-0-028 (2001).
[24] M. M. Maricq. Chemical characterization of particulate emissions from diesel engines: A review, *Journal of Aerosol Science* 38, (2007) 1079-1114.
[25] C. P. Wong, T. L. Chan and C. W. Leung, Characterization of diesel exhaust particle number and size distributions using mini-dilution tunnel and ejector diluter measurement techniques, *Atmospheric Environment* 37**,** (2003) 4435-4446.
[26] T. Kawai, Y. Goto and M. Odaka, Influence of dilution process on engine exhaust nano-particles *SAE paper* No. 2004-01-0963 (2004).

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