Effect of Exhaust Gas Flow and Back Pressure on Urea Dosing Unit and Pipe of SCR in Industrial Diesel Engine

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***Abstract*—Although technology development for electric vehicles and hydrogen vehicles is important from mid to long-term perspective. Efforts to improve the emission and efficiency of internal combustion engine (currently leading the automobile market) vehicles, are important for improving air quality and greenhouse gas. It is expected that the development of various technologies to reduce nitrogen oxides (NO_x) will also be accelerated in line with the global resolution of environmental problems and the strengthening of environmental regulations. Among them, Selective Catalytic Reduction (SCR) is a technology that converts NO_x into harmless N_2 and H_2O by using ammonia as a reducing agent, one of the air pollutants. Due to various advantages, it is the most representative technology for reducing NO_x among the developed technologies. Recently, SCR technology is attracting attention due to stricter NO_x emission regulations around the world. In this paper, the design of the mixer and mixer pipe of the exhaust gas post-treatment device SCR was optimized through flow analysis, and the effect on the flow and back pressure of exhaust gas was studied by conducting an experimental study using a diesel engine and an engine dynamometer. According to the design change of the pipe and mixer, the SCR Uniformity Index was confirmed to be 96.1% and 97.4% before and after the improvement, respectively, confirming that the flow of combustion gas is uniformly distributed. As the exhaust flow rate increased, the back pressure increased rapidly.**

***Index Terms*—SCR, swirl, urea spray, deposit, universal angel**

I. Introduction

It would take long time to completely replace cars to electric and hydrogen cars, and the reality is that quality of air cannot be improved in an instant. Although technology development for electric vehicles and hydrogen vehicles is important from mid to long-term perspective, efforts to improve the emission performance and efficiency of internal combustion engine vehicles, which are currently leading the automobile market, are very important for air quality improvement and greenhouse gas reduction. According to the International Energy Agency, by 2030, 90% of the world's vehicle will be powered with internal combustion engines. Internal combustion engines also include hybrids and plug-in hybrids, which are classified as eco-friendly vehicles, but there is no denying that they are based on fossil fuels. The reality is that vehicles based on internal combustion engines, including hybrid vehicles, account for more than 80% of new car sales, and is expected to account for more than 50% by 2050 [1].

There are many problems that need to be solved before eco-friendly green cars (EV, FCEV) are used. Though, electric vehicles are clean, but efforts to reduce greenhouse gas emissions, GHG are generated in the process of electricity production, such as coal-fired power, and performance improvement of batteries, etc. are required. Reduction efforts should be made together. For more than a few decades, current or improved internal combustion engine vehicles will dominate the roads, and in the automotive industry, internal combustion engine-based vehicles will serve as cash cows for more than a few decades. Green cars such as electric vehicles are expected to occupy the place where internal combustion engines have declined [2,3].

Recently, to improve the air quality around the world, gas emission regulations are strictly applied according to the size of the engine for non-road mobile machinery. In Europe, Stage I, II, III, and IV established by the European Parliament and the Board of Directors are implemented, and Stage IV is being used currently. EPA Tier I, II, III, IV announced by the US Environment Protection Agency (EPA) is applied sequentially, and Tier IV is currently being applied [4]. From 2019, the EU introduced Stage V emission gas regulations that are stronger than the existing Stage IV for non-road mobile equipment (construction equipment, mining machinery, agricultural machinery, etc.). As the seriousness of abnormal climate phenomena, global warming and fine dust problems caused by air pollution problems in Europe as well as in the world is increasing day by day, regulations on diesel engine exhaust gas which is the main cause of pollution, are expected to be strengthened.

The US Department of Environment is planning to apply Tier V, including emission regulations, fuel economy and CO_2 regulations in 2020, and in the case of China, is introducing out many policies to reduce serious air pollution. In the case of Korean automakers, they are

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manufacturing finished cars by applying their own environmental regulations (De-Tier) to respond to air pollution such as fine dust. This is a regulatory value between Stage 5 of European environmental regulations and Tier 4 of US environmental regulations. In 2014, the global construction equipment market was valued at USD 159.1 billion and has grown at an average annual rate of 7.4% since 2000, with the United States accounting for 33%, Japan 22.8%, China 13.3%, and Korea 5.1%. The Korean construction equipment market is an export-intensive industry with a production value of 200 billion won as of 2015 and a very high export ratio (about 70%) to production.

As a study for reducing exhaust gas of diesel engine, Samuelsson [5] and others analyzed the Urea conversion efficiency according to the droplet size of Urea and the injection angle of the SCR injector. As a result of the analysis, it was suggested that the Urea conversion efficiency increases as the spray angle increases and the droplet size decreases. Recent Urea/SCR technology is mostly focused on the study of CHA structure zeolites. BASF has developed a technology for CuSSZ-13 with a pore opening of 3.8 Å. PNNL research team [6] showed that the CuSSZ-13 catalyst reduced NOx in a wider temperature range compared to other zeolite catalysts. In particular, it was confirmed that the generation of N_2O, a greenhouse gas having a global warming potential (GWP) of about 300 times that of CO_2, was very small.

Raul. F. Lobo's research team [7,8] confirmed that the CuSSZ-13 catalyst has very high hydrothermal stability compared to the CuZSM5 catalyst, which has been attracting attention as an NH_3/SCR catalyst. Therefore, it was suggested that structural collapse due to de-alumination, the biggest difficulty in the application of catalysts for exhaust gas purification of zeolite catalysts, could be solved through the application of SSZ-13.

Runduo Zhang research group [9] prepared nano-sized LaMn1-xCuxO_3 perovskite catalysts with high specific surface area by reactive grinding, and studied their properties by NO+O_2 TPSR in C_3H_6/He flow. was performed. Subsequently, a study was conducted on a catalyst for the selective catalytic reduction (SCR) of NO by C_3H_6 in the presence or absence of oxygen.

Hitachi shipbuilding company developed a nitrogen oxide removal catalyst and installed and operated a total of 206 SCR processes in Japan and overseas, and they also possess the technology to continuously produce plate-type catalysts. Ken-ichi Aika's research group [10] conducted a study on the reaction effect of the platinum nanocrystal catalyst structure on the lean-burn reduction reaction of NO by C_3H_6. It has been reported that the edges, corners, torsion and surface defects of polycrystalline platinum particles are the major factors affecting the overall catalytic activity for NO_x conversion.

AMMINEX/Furecia in Europe and PNNL in the US are developing Solid SCR technology that directly pyrolyzes solid ammonia rather than urea water. Solid SCR technology has the advantage of excellent NO_x reduction efficiency even under low exhaust gas temperature. Johnson Matthey has developed and commercialized SCR catalyst and system (SINO_x system). Hanna Harelind's research group [11,12] conducted a study on EtOH/SCR of Ag/alumina and found that isocyanate produced by NH_3 formed in 4wt% Ag/Al_2O_3 catalyst improves the performance of SCR were reported in the study.

Lee *et al.* [13] compared the heat transfer efficiency of aluminum and polycarbonate and investigated the surface temperature of the supercharger, an intake supercharging device, by material. The surface temperature and internal temperature of the polycarbonate and aluminum superchargers were similar in the case where the propeller was installed in the supercharger and in the case where the propeller was not installed, indicating that the propeller had little effect on the temperature. Therefore, as a result of installing an aluminum supercharger with excellent thermal conductivity to the vehicle and analyzing the exhaust gas, HC and NOx decreased when the supercharger was installed regardless of loop conditions.

Lee *et al.* [14], researched on gas injection system that can supply ammonia gas directly to the exhaust pipe by heating and sublimating solid ammonia storage material for solid SCR. The injection nozzle shape, position, presence/absence of mixer, can angle, mixer shape, and A computational fluid analysis was performed to examine the location as a variable, the misdistribution index, the flow uniformity index, and the pressure drop. According to the analysis results, when the mixer is applied, the mixer with 4 blades can reduce the pressure drop without worsening the flow uniformity and distribution of ammonia gas, compared to the mixer with 8 blades.

Park *et al.* [15] studied a spark arrester-integrated SCR mixer that can simultaneously perform mixing and separation roles by combining an SCR mixer and a spark arrester. Two effects were confirmed: the spark arrester attached to the silencer was removed, and the installation space of the exhaust pipe could be secured and cost reduction. It was confirmed that the pressure loss, mixing performance, and collection performance were improved compared to the existing one. Through flow analysis, the collection performance of flammable particles, the mixing performance of ammonia and exhaust gas, and the pressure loss for various cases were numerically calculated, and the optimal design of the S-mixer was selected in consideration of the predicted results.

In the SCR system applied to large diesel vehicles, problems such as blockage of the injection nozzle of the urea water injection system, malfunction of the injection device, and crystallization of urea water in the mixer and catalyst carrier are occurring. In addition, it is known that in a vehicle in which the urea water system operates normally, the catalyst carrier deteriorates and the NOx reduction performance deteriorates. Therefore, Park *et al.* [16] studied the exhaust gas characteristics according to change in mileage in a large diesel vehicle, applying SCR device. The aging catalyst increased the NO_X emission and PM emission due to the deterioration of the NH_3 storage performance of the SCR. When the catalytic driving distance increased, the NH_3 obstruction performance of the SCR catalyst and the NH_3 reduction performance of the AOC decreased, resulting in a sharp increase in NH_3-Slip.

In this study, the mixer and mixer pipe design of the DOC and SCR after-treatment devices for exhaust gas are optimized through flow analysis. Experimental research is conducted using diesel engine and engine dynamometer, and the effect of exhaust gas flow and back pressure is to be understood.

II. Computational Fluid Dynamics

A. Simulation Model Design

The Urea Dosing Module and Mixer System were installed at the rear end of the DOC, and the DOC and SCR were located in a cross shape at the center of the DOC. In addition, the bracket is mounted on the chassis frame of the car, and the SCR has 4 points and the DOC has 2 points. Flow analysis was performed using Star-CCM+, a commercial software. Back pressure was calculated from the DOC inlet part to the SCR outlet part, and the Uniformity Index was calculated at 10mm from the front end of the SCR to determine the homogeneity. After the initial concept design, the analysis model changed the Cone insertion at the rear end of the DOC, the dosing part installation change, the mixer Pipe/ mixer change, and the SCR inlet part perforated pipe. As shown in Fig. 1, the initial concept design is called Model1 and the final design is called Model 2.

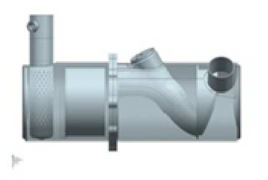
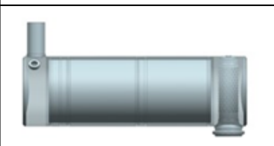
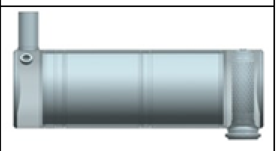
	Model1	Model2
DOC Part		
SCR Part		

Figure 1. Simulation model of DOC and SCR.

B. Analysis Boundary Condition

As shown in Fig. 2 in the boundary condition, the flow rate of the inlet part was 415 kg/h and the temperature was 450 ℃, and simulation analysis was performed. In the case of analysis, it is difficult to actually implement and analyze the substrate, and if it is directly analyzed, the number of computational grids increases rapidly, making it difficult and time consuming to perform practical calculations. The porous medium method was used to simulate the pressure loss to the catalyst, and in the porous (Catalyst) region, the analysis was carried out assuming that the flow proceeds only from the inlet to the outlet.

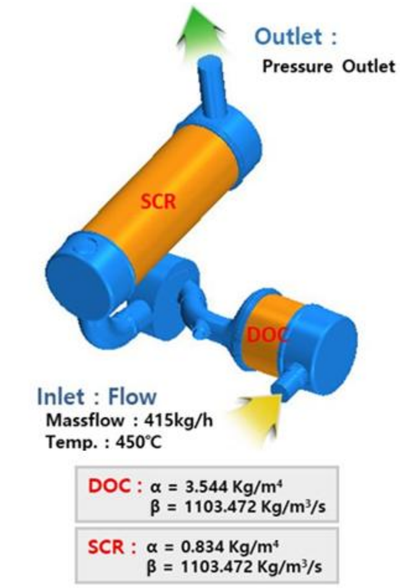
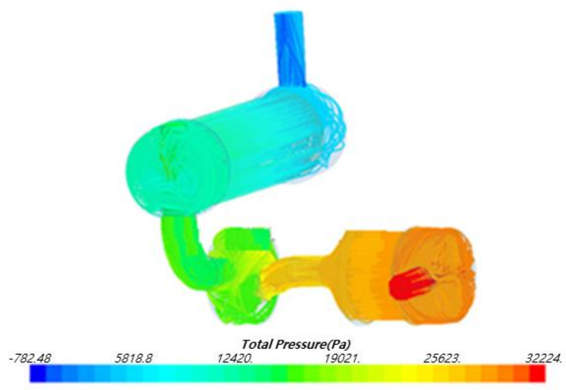


Figure 2. Simulation fluid analysis conditions.

C. Fluid Analysis Result

The pressure difference between DOC and SCR was calculated based on the flow analysis results. In consideration of NH_3 generation and deposit during urea dosing, the flow rate of exhaust gas was increased by improving the urea dosing part and mixer pipe, and the end of the mixer pipe and the swirl plate were changed to lower the back pressure. As a result, the back pressures of Model 1 and Model 2 were 26.9 kPa and 22.2 kPa, respectively.

In the analysis result of Model 2, as shown in Fig. 3, as a result of calculating the pressure difference from the inlet to the outlet part by streamline, the pressure difference from the inlet part to the outlet part was 22.2 kPa.



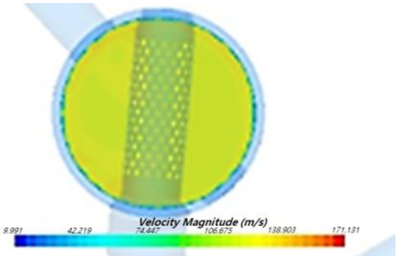
Section 1-2	Section 2-3	Section 3-4	Section 4-5	Section 5-6	Total
2.5 kPa	1.0 kPa	12.7 kPa	4.7 kPa	1.4 kPa	22.2 kPa

Figure 3. Pressure difference for each part.

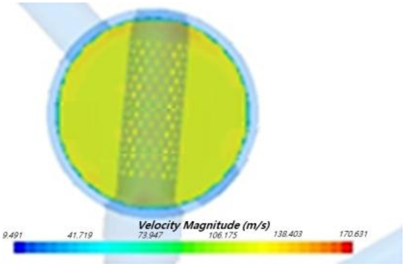
The uniformity index was calculated at 10 mm of the front end of the SCR catalyst. As a result, the SCR Uniformity Index for Model 1 was 96.1%, and the SCR Uniformity Index for Model 2 was 97.4%. The analysis results are shown in Fig. 4, and these results confirmed that the pipe and mixer design changes made the flow uniform.

The NH_3 uniformity was calculated at the rear end of the SCR by spraying urea from the dosing module during urea spraying. After the initial concept design, the analysis model changed the shape of the cone insertion and the dosing part at the rear end of the DOC, and the shape of the mixer pipe and mixer. Mass flow and temperature of the inlet part were set at 415 kg/h and 450 ℃, respectively, and analysis boundary conditions were set by spraying urea at 2 Hz and urea dosing rate 200 mg/s in the dosing part.

As a result of urea spray analysis, the average NH3 uniformity for Model 1 was 95.4%, and the average NH3 uniformity for Model 2 was calculated as 96.4%. As shown in Fig. 5, the highest peak values were 98.1% and 99.1% for Model 1 and Model 2, respectively.

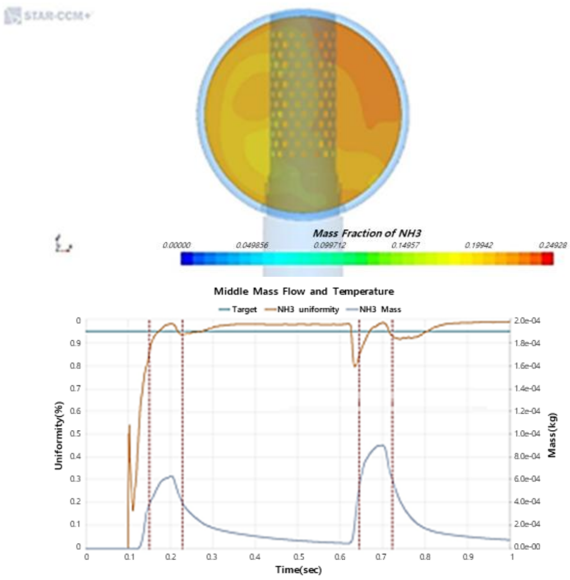


(a) Model 1 SCR Uniformity index: 96.1%.

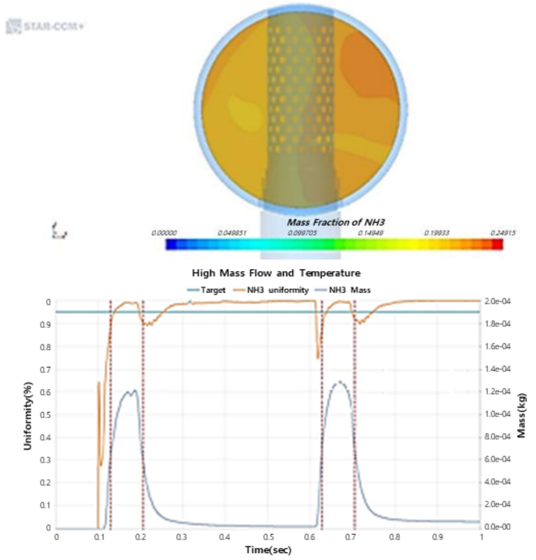


(b) Model 2 SCR Uniformity index: 97.4%.

Figure 4. SCR uniformity index after model design change.



(a) Model 1 SCR Uniformity index: 95.4%.



(b) Model 2 SCR Uniformity index: 99.1%.

Figure 5. Calculation result of NH_3 uniformity for SCR.

III. EXPERIMENTAL TEST

The experimental apparatus of this study consists of an experimental engine, engine dynamometer, exhaust pressure sensor, exhaust flow meter, and temperature sensor, and the configuration diagram of the experimental apparatus is shown in Fig. 6. Exhaust temperature was measured at 4 locations (exhaust manifold, before and after the aftertreatment device and exhaust muffler). Considering that the maximum withstand temperature of the exhaust flow meter is 250 ℃, the pipe length is longer than that of the exhaust system in the existing vehicle so that the exhaust gas can be cooled.

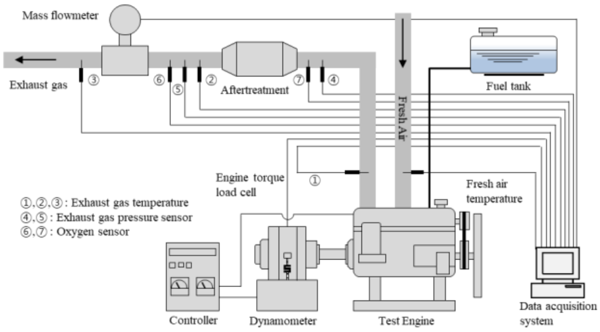


Figure 6. Experimental test setup.

A. Simulation Model Design

The engine used is a CRDI (Common Rail Direct Injection) diesel engine, with smoke reduction and filtration device that meets the Euro 5 emission standards was used. This engine has a maximum fuel injection pressure of 2000 bar and is an in-line four-cylinder water-cooled engine. The displacement is 1995cc, and the cylinder head of the experimental engine has a DOHC (Double Over Head Cam Shaft) structure. It is equipped with an Electronic Fixed Geometry Turbocharger (E-VGT) and has a maximum compression ratio of 16.0:1.

The main engine specifications used in the experiment are shown in the Table I.

TABLE I. TEST ENGINE SPECIFICATION

Description	Specification
Engine type	In-line, DOHC, D2.0 TCI-R
No. of cylinder	4
Bore/Stroke(mm)	84.0/90.0
Displacement(cc)	1995
Compression ratio	16.0: 1
Fuel injection system	CRDI
High injection pressure	2000bar
Turbocharger	E-VGT

In addition, to keep the coolant temperature constant, a water supply and a coolant tank were installed to keep the coolant temperature supplied to the engine constant at 90 ℃. The cooling water temperature was monitored using K-type thermo-couple sensors at 4 cooling water hoses. In order to absorb the torque generated from the engine, an eddy-current electronic dynamometer that can be controlled is used. The eddy-current electronic dynamometer is used after forming a magnetic flux by supplying current to the excitation coil of the casing. When an inductor rotating plate is rotated by a prime mover in this magnetic field, an eddy current is generated in this rotating plate. Braking force is generated on the rotating plate of the dynamometer by this current, and the mechanical rotational energy generated by the engine is converted into thermal energy to absorb power. The main specifications of the engine dynamometer are as shown in Table II.

TABLE II. ENGINE DYNAMOMETER SPECIFICATION.

Description	Specification
Dynamometer type	Eddy-current electro
Cooling system	Water cooled
Max. absorbing(kW)	200kW
Max. absorbing shaft speed (rpm)	7,000 rpm
Torque indicator	Electro panel digital indicator

B. Experimantal Condition

The engine dynamometer test was conducted for DOC, SCR, and DOC/SCR, and a straight pipe was installed in the part where the aftertreatment system was conducted, and the difference in back pressure before and after the straight pipe was confirmed. First, each individual unit of the post-processing device was performed first, and finally, the DOC/SCR assembly test was performed. The experimental aftertreatment system is shown in Fig. 7.

As shown in Table III, the engine load factor and engine rotation speed according to the 7 cases of changing acceleration are respectively shown. Data were measured every 400 rpm based on the engine speed. The data was measured three times for each condition and the average was obtained.

Figure 7. Individual parts and assemblies for engine testing.

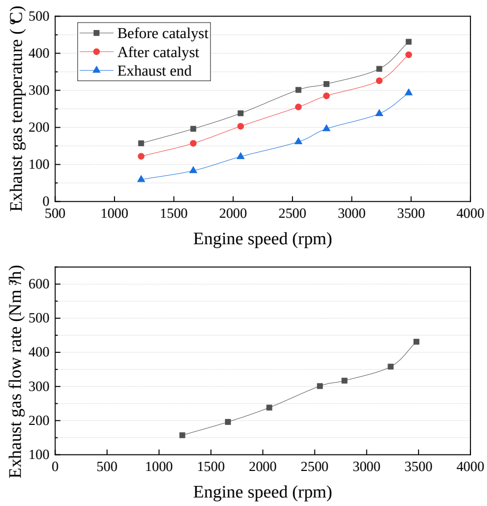
TABLE III. EXPERIMENTAL CONDITION

No.	Acc. Pedal (%)	Load (Nm)	Engine speed (rpm)
1	8	10	1200
2	12	15	1600
3	16	20	2000
4	20	25	2400
5	24	30	2800
6	28	35	3200
7	32	40	3400

C. Experimantal Results

The DOC was installed in the test engine, and the results of the test according to the test conditions are shown in the Fig. 9. The exhaust temperature and back pressure before and after the after treatment system were measured, and the exhaust flow rate was measured 1m before the exhaust pipe.

As shown in the Fig. 8 below, the exhaust temperature, exhaust flow rate, and back pressure all tended to increase according to the engine speed. When the engine rotation speed was about 3450 rpm, the exhaust gas temperatures before and after the catalyst were 431 ℃ and 396 ℃ respectively. As the engine speed increased, the temperature difference between the exhaust gas before and after the catalyst gradually decreased. The maximum exhaust flow rate under experimental measurement conditions was 431 Nm^3/h. The pressure difference before and after the catalyst increased more rapidly at 2500 rpm. It was confirmed that the back pressure also increased as the exhaust flow rate increased.



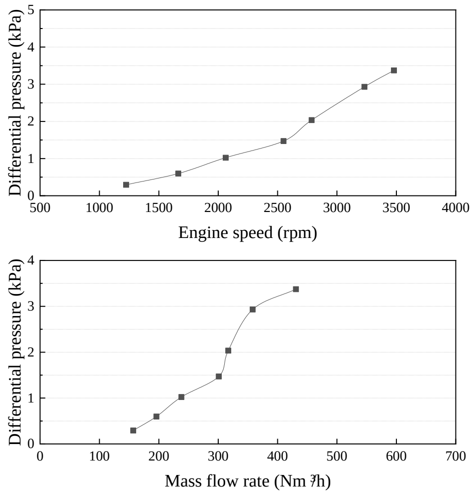


Figure 8. Mass flow rate and differential pressure of DOC aftertreatment using engine dynamometer.

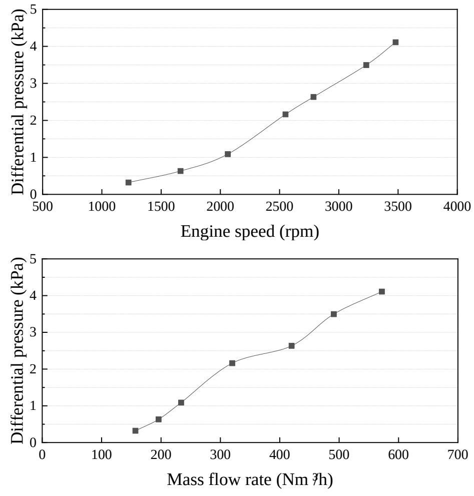
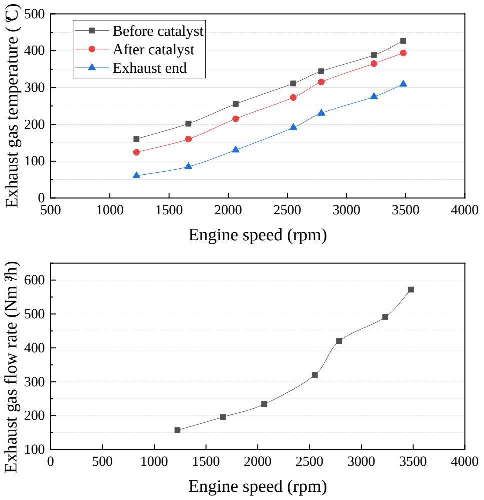


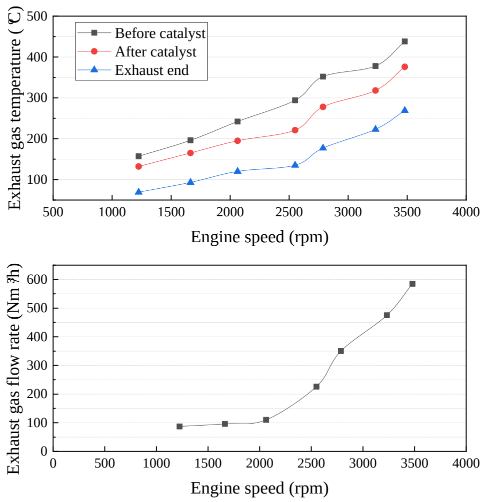
Figure 9. Mass flow rate and differential pressure of SCR using engine dynamometer.

In the second experiment, only the SCR catalyst was mounted and the same experimental method and experimental conditions were used. As shown in Fig. 9, the exhaust gas temperature, exhaust flow rate, and back pressure increased as the engine speed increased. The SCR catalyst showed that the flow rate and back pressure increased rapidly from 2500 rpm. The exhaust gas temperature in front of the SCR was about 425 ℃ at the engine rotation speed of 3450 rpm, and the exhaust flow rate and exhaust pressure difference were 572 Nm^3/h and 4109 Pa, respectively. Although the diameters of SCR and DOC were similar, the pressure difference before and after SCR catalyst was higher than that of DOC because the length of SCR was long.

In addition, as the length of the catalyst is increased, the exhaust gas is cooled by the surface during movement, and it can be seen that the temperature difference before and after the catalyst is wider than that of the DOC catalyst.



An optimized diesel engine DOC/SCR assembly was installed and the experiment was conducted under the same conditions as above. As the engine speed increased, the temperature increased. The difference in temperature between the front and rear end of DOC/SCR was 62 ℃, and the temperature difference was larger than that of the single test (only DOC, only SCR). Also, when the exhaust gas temperature was high, the temperature difference was larger. At around 3450 rpm of engine speed, the exhaust gas temperature at the front end of the prototype was about 438 ℃, and the exhaust flow rate and exhaust pressure differential were 585 Nm^3/h and 17,714Pa, respectively. The result is shown in Fig. 10. Also, unlike the single unit, the back pressure increased rapidly as the exhaust flow rate increased, which is thought to be due to the rapid increase in the back pressure as the SCR and DOC catalysts are continuously connected.



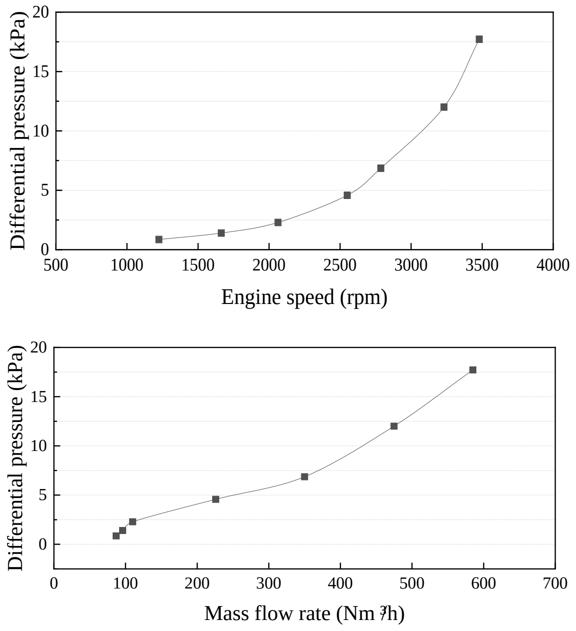


Figure 10. Mass flow rate and differential pressure of DOC/SCR using engine dynamometer.

IV. Conclusion

In this study, with the help of flow analysis, the mixer and mixer pipe design of the DOC and SCR of the exhaust gas post-treatment system was optimized, and the effect on the flow and back pressure of the exhaust gas was identified by conducting an experimental study using a diesel engine and an engine dynamometer.

- Considering NH_3 generation and deposit during urea dosing, the urea dosing part and the mixer pipe part were optimized and designed, and the flow rate of the exhaust gas was increased by performing simulation flow analysis.
- It is necessary to lower the back pressure for the smooth discharge of the combustion gas. After improving the design of the mixer pipe end and the swirl plate to lower the back pressure, it was confirmed that the exhaust gas pressure was lowered by 4.7 kPa in the flow analysis.
- According to the design, change of the pipe and mixer, the SCR Uniformity Index was confirmed to be 96.1% and 97.4% before and after the improvement, respectively, confirming that the flow of combustion gas is uniformly distributed.
- Unlike the single unit, the back pressure increased rapidly as the exhaust flow increased, which is thought to be due to the rapid increase in the back pressure as the SCR and DOC catalysts were continuously connected.
- At the same engine speed as the DOC, the exhaust flow rate was similar, but the back pressure of the SCR was lower than that of the DOC. It is considered that the back pressure was lowered due to the difference in diameter even though the length of the catalyst was similar.

Conflict of Interest

The authors declare no conflict of interest.

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References

[1] I. Lopez, E. Ibarra, A. Matallana, J. Andreu, and I. Kortabarria, "Next generation electric drives for HEV/EV propulsion systems: Technology, trends and challenges," *Renewable and Sustainable Energy Reviews*, vol. 114, 2019.

[2] Y. M. Goo, "Technology for hydrogen fuel cell electric vehicle," *AUTO JOURNAL: Journal of the Korean Society of Automotive Engineers*, vol. 42, no. 2, pp. 33-36, 2019.

[3] S. J. Kim, S. M. Hong, and K. H. Nam, "Recent progress trend in motor and inverter for hybrid vehicle," *The Transactions of Korean Institute of Power Electronics*, vol. 21, no. 5, pp. 381-387, 2016.

[4] K. B. Lee and K. C. Oh, "NOx emission characteristic according to aging of EGR cooler in non-road diesel engine," *Journal of the Korean Society for Power System Engineering*, vol. 20, no. 5, pp. 37-45, 2016.

[5] L. H. Lim, Y. B. Yoon, C. S. Song, Y. J. Park, S. W. Lee, and Y. S. Cho, "A numerical analysis on distribution of reductant with mixer application and various injection method in urea-scr system," in *KSAE Spring Conference Proceedings*, pp. 130-135, 2010.

[6] J. Szanyi, J. H. Kwak, H. Zhu, and C. H. F. Peden, "Characterization of Cu-SSZ-13 NH3 SCR catalysts: An in situ FTIR study," *Physical Chemistry Chemical Physics*, vol. 15, no. 7, pp. 2368-2418, 2013.

[7] B. Ipek, R. A. Pollock, C. M. Brown, D. Uner, and R. F. Lobo, "H2 Adsorption on Cu(I)−SSZ-13," *The Journal of Physical Chemistry C*, vol. 122, pp. 540-548, 2018.

[8] T. D. Pham and R. F. Lobo, "Adsorption equilibria of CO2and small hydrocarbons in AEI-, CHA-, STT-, and RRO-type siliceous zeolite," *Microporous and Mesoporous Materials*, vol. 236, pp. 100-108, 2016.

[9] R. Zhang, H. Alamdari, and S. Kaliaguine, "SO2 poisoning of LaFe0.8Cu0.2O3 perovskite prepared by reactive grinding during NO reduction by C3H6," *Applied Catalysis A: General*, vol. 340, pp. 140-151, 2008.

[10] K. Aika, "Role of alkali promoter in ammonia synthesis over rutheniumcatalysts—Effect on reaction mechanism," *Catalysis Today*, vol. 286, pp. 14-20, 2017.

[11] H. Kannisto, M. Skoglundh, K. Arve, E. Olssonc, and H. Harelind, "Direct observation of atomically-resolved silver species on a silver alumina catalyst active for selective catalytic reduction of nitrogen oxides," *Catalysis Science & Technology*, vol. 9, no. 22, pp. 6201-6534, 2019.

[12] L. Strom, P. A. Carlsson, M. Skoglundh, and H. Harelind, "Surface species and metal oxidation state during H2-Assisted NH3-SCR of NOx over alumina-supported silver and indium," *Catalysts*, vol. 8, no. 1, 2018.

[13] J. H. Lee, S. W. Kim, and H. K. Yoon, "Analysis on temperature change of super changer for the reduction of auto exhausts gas," *Journal of Ocean Engineering and Technology*, vol. 27, no. 1, pp. 109-114, 2013.

[14] H. Y. Lee, C. S. Yoon, and H. S. Kim, "CFD analysis on gas injection system of solid SCR for nox reduction of exhaust emissions in diesel engine," *Transaction of the Korean Society of Automotive Engineers*," vol. 22, no. 5, pp. 73-83, 2014.

[15] S. J. Park, Y. H. Ryu, D. H Lee, H. S. Lee, and D. Y. Lee, "Design of a spark arrester integrated SCR mixer for medium-speed engine," *Transactions of the Korean Society of Mechanical* Engineers – *B*, vol. 45, no. 3, pp. 181-188, 2021.

[16] G. Y. Park, M. J. Kwon, J. Y. Jung, H. Y. Song, K. H. Kim, and S. W. Lee, “A study on the performance change of SCR system for heavy-duty diesel vehicles,” *Transaction of the Korean Society of Automotive Engineers*, vol. 27, no. 5, pp. 405-409, 2019.

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