

# Study of the Optimization of the SCR Catalyst Position in by Exhaust System of using Mixer

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## Abstract

**Background/Objectives:** This research analyzes the influence of Urea SCR System's mixer and optimization of the Catalyst's position through post technologies in order to satisfy the Euro 6 regulations. **Methods/Statistical Analysis:** The simplified modeling was facilitated to interpret the current exhaust system. Considering the latter as the background, ANSYS was used for the Analysis. As for the method of Analysis, 5 flux variables were considered from exhaust flux of 1,000rpm~3,000 rpm in increments of 500 rpm. **Findings:** When the flux passes through the mixer, the speed dispersion increased and as the rpm increased, the results showed that 1,000 rpm compared to 3,000 rpm, the back pressure elevated over 500 Pa. By assessing the degree of uniformity, the uniformity expanded faster at high rpm and in low rpm, the flux itself is low so the uniformity gradually increased as it reached the latter part. Overall efficiency of over 95% was achieved at approximately 15~20 cm and in the points after that, the degree of uniformity gradually decreased in the graph. Therefore, it was determined that optimal position for the SCR catalyst should be 20~50 cm from the posterior of the mixer. **Application/Improvements:** This research was analyzed of the distribution uniformity effect in the exhaust system, the analysis result could be optimized of catalyst-position and improved uniformity index.

**Keywords:** Back Pressure, Exhaust System, Mixer, SCR Catalyst, Uniformity Index

## 1. Introduction

Due to the increase in regulation demands, post technologies geared toward downsizing, which consists of increasing fuel efficiency or output using equivalent engine capacity, is being widely studied<sup>1,2</sup>. Technologies that can satisfy the fortified NO<sub>x</sub> exhaust emission regulations of Euro 6 include LP EGR, LNT, and Urea SCR. The LP EGR consists of recirculating the exhaust gas from the rear part of the exhaust gas DPF to the engine in order to decrease the amount of NO<sub>x</sub>. In the past, the use of LP EGR itself was able to satisfy the Euro 5 regulations, however, to satisfy the current Euro 6 regulations, technologies such as LP EGR + LNT, SCR are needed. In the case of LNT, it uses fuel as a reducing agent to break down the constituent through chemical reactions in order

to make it harmless to the human body. Although, it is not as efficient as the SCR, if used in combination with the LP EGR, it can satisfy the current exhaust regulations. The cost is cheaper than the SCR system; however, it has a downside of decreased fuel efficiency that comes with using fuel as a reducing agent. Because of the latter, diesel cars, displaying high fuel efficiency as an outstanding upside, are faced with critical limitations<sup>3-5</sup>.

The SCR system sprays the urea solution by attaching the Urea Injector and tank in the exhaust line. Then the chemical reaction occurs in the SCR catalyst to make NO<sub>x</sub> into harmless N<sub>2</sub> H<sub>2</sub>O for emission. Systems such as this are higher in cost compared to the LNT equipment because it needs additional components in its structure. However, it has shown much better performance in the side of exhaust gas efficiency<sup>6</sup>. Currently, there are many

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studies aimed to find the optimal position for the injector, mixer, and SCR catalyst of the SCR system in order to decrease the cost of the system. However, this is difficult to test within the actual exhaust system<sup>7</sup>.

Therefore, this research tries to find the optimal position for the SCR catalyst by using the commercial program ANSYS to consider the circulation of exhaust gas and to calculate the flux.

## 2. Analysis Method

### 2.1 Research Model

Figure 1 is schematic diagram of the exhaust system and the SCR System positioned in ⑤~⑧ of the figure. The role of the DPF is to reduce the PM of the exhaust gas and the role of the EVV is to block the flux of the exhaust to secure the flux flowing to the LP EGR. Also, the exhaust gas that passes through the EVV goes through the fuel passage of the SCR system. At this point, the pressure maintained over 5~6 bar from the Urea tank shoots out at 5 bar from the injector and the urea resolution sprays out as well. The mixed exhaust gas from the mixer goes through a chemical reaction in the SCR catalyst to reduce NO<sub>x</sub>.

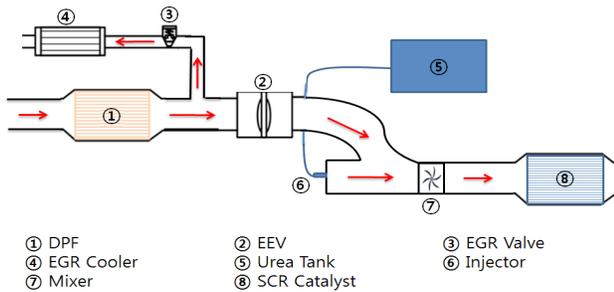


Figure 1. Exhaust system schematic.

### 2.2 Analysis Condition and Methods

In this study the SCR flux line positioned in the rear of EVV is 3D modeled to make it look similar to the actual model using CATIA V5. Figure 2 is the actual exhaust system line that is being used and Figure 3 is the simplified model for the floating analysis. Overall, the model has been simplified by making the rear part of the mixer a straight line and fixing the angle of the model's injector and exhaust entrance. For the inlet conditions, the

mass flow rate was calculated and entered. To substitute the mass flow rate, an increment of 500 rpm throughout 1,000 rpm~3,000 rpm was set under the temperature condition of 300°C. With regards to the injector's setting conditions, water was selected as the material property of the substance and entry speed 24 m/s of mass flow rate was inserted as 0.00086 kg. The reason for selecting water as the material property is because about 70% of urea is liquid and therefore, for the simplicity of the interpretation, water was chosen in substitution of urea. For the exhaust line 1, atmospheric pressure of air pressure as an open formation.

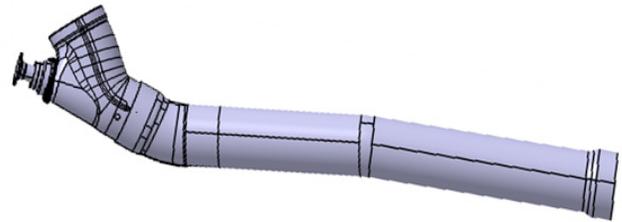


Figure 2. Real exhaust line modeling.

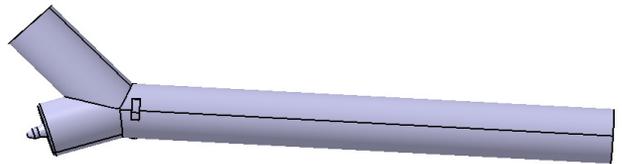


Figure 3. Exhaust flow line modeling.

During the analysis, SUS (Stainless Steel) 405 used as the material and the material property is shown in Table 1. Table 2 shows the mass flow rate of each rpm. Equation (1) was used for the calculations.

Table 1. Material of exhaust line

Item	Specification
Material	SUS 405
Density(kg/m3)	7,800
Poisson's Ratio	0.3
Young's Modulus(Pa)	2E+11
Tensile Yield Strength(Pa)	2.76E+08
Tensile Ultimate Strength(Pa)	4.69E+08

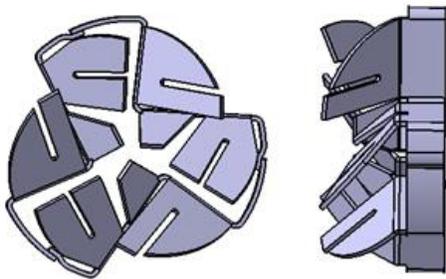
$$M = \rho \cdot R \cdot V / 2 \tag{1}$$

M: Mass flow rate,  $\rho$ : Air density, R: Engine rotating speed, V: Displacement.

**Table 2.** Inlet flow mass late

Engine Rotating speed (rpm)	Specification(kg/s)
1,000	2.16E-2
1,500	3.24E-2
2,000	4.32E-2
2,500	5.40E-2
3,000	6.48E-2

Figure 4 shows the mixer inside the exhaust pipe which was model similar to the actual model. The mixer has 3 blades attached in the center and 6 blades attached externally.



**Figure 4.** Mixer modeling.

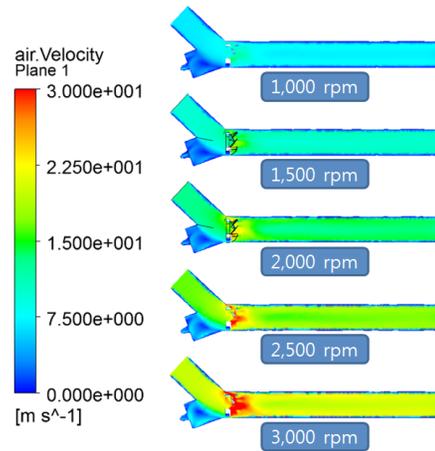
### 3. Result and Considerations

#### 3.1 Velocity Analysis Results

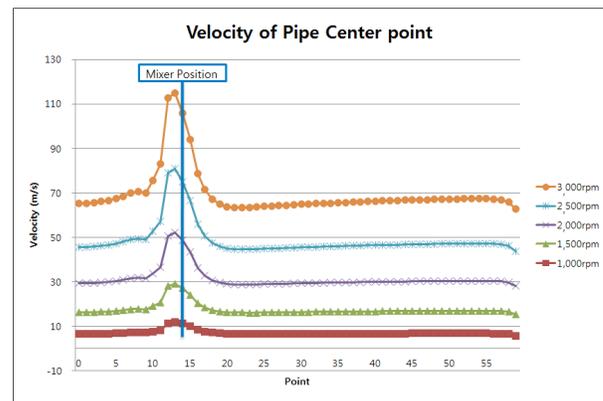
##### 3.1.1 Velocity Analysis from the Exhaust Flux

Figure 5 displays the velocity distribution of the fluid line per rpm. Maximum velocity distribution verified 115 m/s at 3,000 rpm. When passing near the mixer, an increase of the velocity distribution can be identified. Also, swirl was produced in the rear part of the mixer due to the influence from the mixer and the influence of the fluid from the rear part of the mixer became greater as the flux increased.

Figure 6 is a graph that confirmed the velocity in the center for each rpm, and X-axis is point that is exhaust pipe center point from beginning to end each 1cm, Y-axis is velocity distribution. From looking at the graph, the greatest velocity distribution was identified in the anterior of the mixer and the velocity near the mixer increased 1.5 to 2 times in comparison to other exhaust pipes. The velocity of distribution in the rear part of the mixer decreased according to the orifice effect and subsequently, the average velocity increased gradually.



**Figure 5.** Velocity distribution of exhaust gas.



**Figure 6.** Velocity of pipe center point.

##### 3.1.2 Water Velocity Analysis Results

Figure 7 shows the velocity of distribution during the water dispersion per rpm. As the water distribution constantly flows to the back of the mixer, it showed a tendency to spread gradually because the inflow of the exhaust gas is small in the low rpm section. When it gradually goes into the high rpm, the water's overall velocity of dispersion mixed more equally in the back of the mixer after being mixed once in the anterior. Moreover, the phenomenon of it mixing equally in the posterior of the mixer showed a tendency to mix more equally in the low rpm with lower flux.

#### 3.2 Eddy Viscosity Distribution Analysis Results

Figure 8 displays the eddy viscosity distribution analysis results per rpm. Eddy viscosity distribution is a coefficient that demonstrates turbulent transportation in the quan-

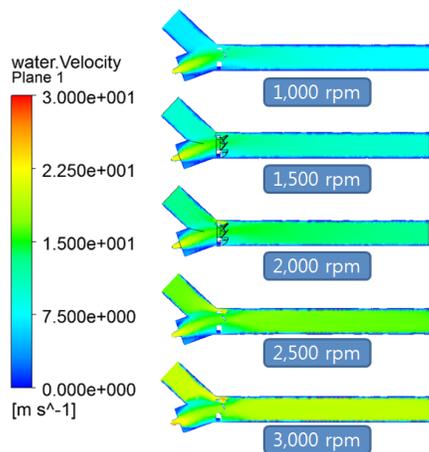


Figure 7. Velocity distribution of water injection.

tivity of motion through the whirlpool that induces internal friction in fluids and generally speaking, distribution density of the substance in the pipe can be figured out through the coefficient of velocity. The eddy viscosity distribution analysis results can identify the tendency of the overall flow within the low rpm section. And maximum eddy viscosity distribution verified 0.03 pa-s at outside pipe from 3,000 rpm. As it gradually approaches the high rpm, the eddy viscosity of each part changes and when the eddy viscosity concept itself is turbulent, each part of the viscosity can be seen. Therefore, these results are displayed because the increase in the turbulent intensity.

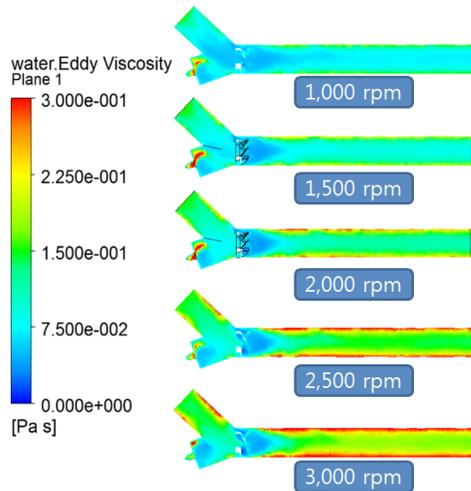


Figure 8. Eddy viscosity of water injection.

### 3.3 Pressure Distribution Analysis Results

Figure 9 displays pressurized distribution analysis results for each rpm. In the low rpm section, almost no changes in the pressurized distribution were found. As the rpm

increases, the back pressure in the anterior of the mixer became larger.

Figure 10 is a graph that confirmed the pressure distribution in the center for each rpm, and X-axis is point that is exhaust pipe center point from beginning to end each 1cm, Y-axis is velocity distribution. Through the analysis of the pressurized distribution, about 1,300 Pa was formed from 3,000 rpm of the back pressure in the anterior and posterior part of the mixer. The fluids developed in the outside of the pipe due to the mixer and therefore, low pressure was created in the back and center part of the mixer. Distinction between maximum pressure and minimum pressure was verified about 4 times each rpm.

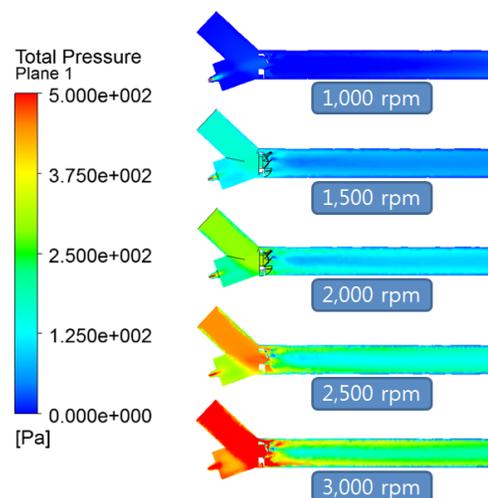


Figure 9. Pressure distribution of exhaust system.

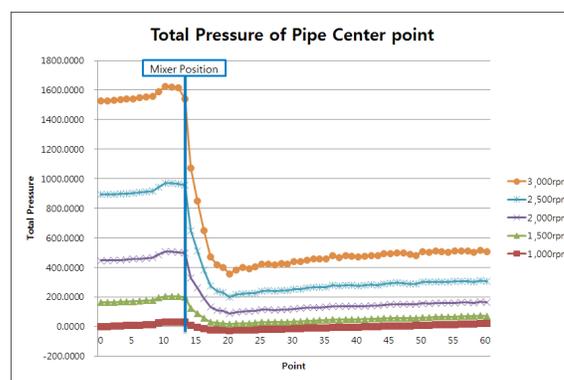


Figure 10. Total pressure of pipe center point.

### 3.4 Uniformity Index Analysis Results

Figure 11 displays the uniformity index results. X-axis indicate distance after mixer, Y-axis indicate analysis result of uniformity index. The numerical value of the

uniformity index had a tendency to decrease as the rpm increased and the maximum efficiency was obtained at 23 cm of 2,000 rpm. Most of the times, the graph increased to about 20 cm and when it reaches the peak, it created a phenomenon of hitting against the wall, and because of this, the degree of uniformity gradually decreased. When assessing the 6~7 cm point, the data takes a big turn in the direction because of the swirl creation from the mixer and this point can be identified as the fluid's first point of intersection.

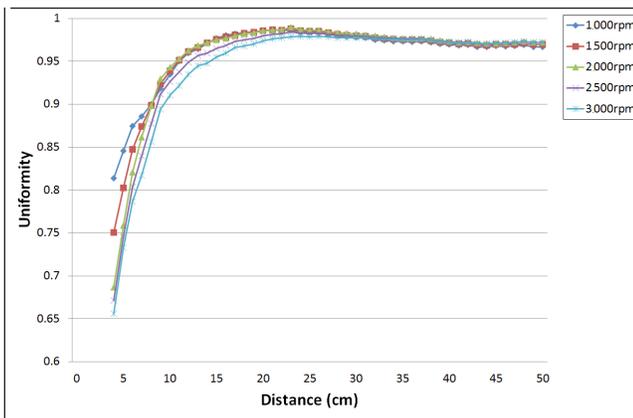


Figure 11. Uniformity of water.

## 4. Conclusions

This research analyzed the optimal positioning of the SCR system catalyst using the commercial program ANSYS because of the difficulty in studying the SCR system within the exhaust system.

- When passing near the mixer, the distribution velocity increased and the difference in maximum and minimum velocity was 1.5~2 times due to the swirl from the posterior of the mixer.
- As the rpm increases, there was a rise of 1,000 Pa back pressure at 3,000 rpm compared to 1,000 rpm. Also back-pressure has a great effect on engine efficiency, maximum back pressure to 1,600 Pa is a very small. Therefore engine is considered to work effectively.
- Looking at the eddy viscosity distribution and pressure distribution, fluid is produced in the anterior of the mixer due to the increase in the rpm. Subsequently, the mixture occurred and

as it passed through the mixer, second mixture occurred.

- Overall, efficiency of over 95% was achieved at approximately 15~20 cm and in the points after that, the degree of uniformity gradually decreased in the graph. Therefore, it was determined that optimal position for the SCR catalyst should be 20~50 cm from the posterior of the mixer.

## 5. Acknowledgment

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