Study on the Flow Effects of an Exhaust System by Mixer Modeling

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Abstract

This study focused on the mixer used in a SCR System, a technology being developed to conform to exhaust gas regulations which have recently become stricter. This study includes an analysis on fluid effect at each mixer to optimize the location of the catalyst and optimized modeling to interpret the current condition of the exhaust system. ANASYS of commercial program was utilized to analyze the fluid effects. Parameters were set up of four variable at 1,000rpm from 1,000rpm to 4,000rpm and three models were used for the analysis. The maximum pressure distribution was measured at mixer 2 and total pressure distribution was measured at mixer 2 as the largest amount, followed by mixer 1 and mixer 3 respectively. Low pressure was measured at the end-central part of the mixer since the pressure is distributed from the central axis and towards the outside. The largest velocity distributional area, 210m/s, was measured at mixer 2 during analysis by velocity. A low velocity region was captured at the end-central part of the mixer since flow was created towards the outside. The analysis showed that mixer 1 was the most effective in pressure distribution and uniformity.
Keywords: mixer, Velocity distribution, Pressure distribution, Uniformity index, SCR System

1 Introduction

These days, the automobile industry is focusing on enhancing engine power and fuel efficiency, reducing costs through downsizing, and conforming intensified exhaust gas regulation. Engine power and fuel efficiency have been greatly enhanced and have already reached the commercialization stage. [1-3] Downsizing of vehicles has led to weight reduction by utilizing engines with less displacement compared to previous engines with the same engine power. Consequentially, fuel efficiency enhancement and cost reduction are clearly on the rise. In addition, development on gas exhaust systems is in serious need to conform to intensified exhaust gas regulations. [4]

As technologies have become more developed to satisfy the US Tier 4 and EURO VI, Diesel Particulate Filter (DPF) reduces the minute particles; and Lean NOx Trap (LNT) as well as Selective Catalytic Reduction (SCR) system to reduce NOx. However, for LNT, total fuel efficiency of a vehicle tends to drop since it uses the fuel as a reducing agent. [4-6] Components of the SCR system includes an injector to spray urea solution, urea tank, urea pump module, SCR Catalyst, and mixer. Even though the cost of automobiles increases when utilizing the SCR system, due to a large number of components needed, it clearly presents advantages in better fuel efficiency compared to vehicles with LNT since it does not use fuel as a reducing agent. [7] For this reason, the direction of market trends of Exhaust systems clearly focuses more on the SCR system these days. Many studies were conducted on the components of the SCR System except for the SCR mixer. Therefore, this study mainly focuses on the mixer in a SCR system to maximize the reduction effect on noxious exhaust gas. [8-9]

This study was conducted using a commercial program ANSYS to optimize the catalyst location according to the analysis on fluid effect and uniformity of the mixer in a SCR system.

2 Methodology

2.1 Analysis Model

Fig. 1 is a schematic diagram of an exhaust system, and the SCR System analyzed on this study is located at 5~8. SCR System has the mechanism that controls the urea injector by controlling a sprayed amount and the injecting timing after receiving exhaust flow date from ECU. The mixer attached at 7 is utilized to increase the efficiency of exhaust flow mixing and the SCR Catalyst is utilized to help the chemical reaction.
2.2 Analysis Condition and Method

In this study, an interpretation was carried out by deforming the shape of the mixer in a SCR System. Fig. 2 shows the shape of SCR mixer 1 with three types of 140-degree blades at the center and six types of 130-degree blades at the outer part. mixer 2 has 8 blades in the same modeling. mixer 3 has 8 blades with 140-degree and 4 blades has a rectangle plate at the center part. The shape of the plates show differences. Exhaust lines with each mixer were made into the same models for commercial use and modeling was simplified to clarify the analysis. Temperature was set to 300℃ for Inlet Setup condition and the flow variable condition was set as in Table 1, four variables at every 1,000rpm from 1,000rpm to 4,000rpm. In addition, water was used instead of urea solution for injector to clarify the analysis since 70% of urea solution is composed of water. Injector pressure of the water was 5 bars with 30℃ of temperature. Material property of the exhaust line used in the analysis was SUS (Stainless Steel) 405 as shown in Table 2.
Table 1. Inlet flow mass rate

<table>
<thead>
<tr>
<th>Engine Revolution Number (RPM)</th>
<th>Specification (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>0.04</td>
</tr>
<tr>
<td>2,000</td>
<td>0.08</td>
</tr>
<tr>
<td>3,000</td>
<td>0.12</td>
</tr>
<tr>
<td>4,000</td>
<td>0.159</td>
</tr>
</tbody>
</table>

Table 2. Material of exhaust line

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>SUS405</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>7800</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Young's Modulus (Pa)</td>
<td>2E+11</td>
</tr>
<tr>
<td>Tensile Yield Strength (Pa)</td>
<td>2.76E+08</td>
</tr>
<tr>
<td>Tensile Ultimate Strength (Pa)</td>
<td>4.69E+08</td>
</tr>
</tbody>
</table>

3 Results and Discussions

3.1 Analysis Result by Flow Rate

3.1.1 Pressure Distribution

Fig. 3 ~ Fig. 6 shows the pressure distribution result at every 1,000rpm from 1,000rpm to 4,000rpm, respectively. Maximum pressure distribution, 7,600Pa, was measured at mixer 2 in 4,000rpm. The largest total pressure distribution of mixers was measured at mixer 2 followed by mixer 1 and then mixer 3, respectively. That is considered that the result was measured as above since mixer 1 and mixer 2 have a point of intersection at the center and only 4 blades in mixer 3 affect the flow at the center part. That is evaluated that mixer 2 showed a larger value than mixer 1 since the blades in mixer 1 have the shape of cracked stems. A larger value of pressure difference at the front part and the end part was measured at a higher RPM according to comparison between Fig. 3 and Fig. 6. Also, a reduction in pressure difference was evident at a lower RPM.

![Total Pressure]

*Fig 3. Pressure result of 4,000rpm*

*Fig 4. Pressure result of 3,000rpm*
3.1.2 Pressure Distribution at Center Point of Inner Pipe

Fig. 7 is picture of total pressure distribution at the center axis. X-axis represents location points from the central point of the front part of the exhaust pipe by 1cm and the Y-axis represents a graph of pressure distribution. The pressure at the front part of mixer 2 was measured with the value of approximately 7,600Pa, which is larger than mixer 1, 7,000Pa, and mixer 3, 6,800Pa. In addition, there was drastic pressure decline near the mixers based on a comparison between the front and the end of mixer since the flow effect by the mixers is created towards the outside, resulting in a drastic decline of pressure at the center part. Pressure differences between the maximum value and the minimum value at each mixer were generally about 6,500 Pa.
3.1.3 Velocity Distribution

Fig. 8 ~ Fig. 11 shows the velocity distribution result at every 1,000rpm from 4,000rpm to 1,000rpm, respectively. Fig. 8 presents that most of the measurement showed a velocity faster than 100m/s at flow regions. There was a low-velocity region at the center part of the pipe since the flow stream is created towards the outside of pipe. In addition, mixer 3 had the clearest low-velocity region at the center part. It was evaluated that the result came out as above since the modeling of the blades has a rectangle plate at the center part which blocks the flow stream. Flow effect for each mixer decreased as RPM decreased and the largest velocity distribution area was measured at mixer 2.
3.1.4 Velocity Distribution at Center Point of Inner Pipe

Fig. 12 is the graphs of velocity distribution at the center part of the inner flow layer. X-axis represents the location points from the central point of the front part of exhaust pipe by 1cm and the Y-axis represents the graph of velocity distribution. Maximum velocity of flow was measured at the front part of each mixer. The values were mixer 1 with 170m/s, mixer 2 with 210m/s, and mixer 3 with 195m/s. mixer 2 showed the largest value. The result came out as above since the back pressure of mixer 2 was the largest and it led to create the largest velocity distribution caused by pressure difference. The difference between mixer 1 and mixer 3 was measured since each blade in mixer 1 was separated into three inner blades and six outer blades, and a smooth flow stream was created by a pipe conduit. When measured at the end part of the mixer, mixer 3 presented the lowest value at the center part due to the shape of the plate being formed as rectangular at the center part which blocked the flow stream. Velocity differences at each mixer decreased as rpm decreased.

![Graphs of Velocity Distribution](image)

Fig 12. Velocity distributions of center point

3.2 Uniformity Analysis Result of each Mixer

Fig. 13 is a picture of the characteristics of the mixer. X-axis represents the distance from the end part of the mixer, and the Y-axis represents the uniformity index from the analysis results. For mixer 1, the uniformity index gradually increased and reached a uniformity of 95% at the 12~15cm region. A large value
of uniformity was measured as RPM decreased. For mixer 2 and mixer 3, uniformity and uniformity distribution were evenly measured for all cases.

![Graph](image1.png)

**Fig 13. Result of mixer characteristic**

### 4. Conclusion

This study was conducted with the application of the commercial program, ANSYS, due to difficulty in analyzing the influence of a mixer in a SCR system. It includes an analysis on flow distribution and uniformity at each mixer and draws a conclusion as below from the analysis results:

- The largest value of back pressure at the front part of the mixers was mixer 2 followed by mixer 1 and then mixer 3, respectively. Back pressure at the front part of the mixer is the factor that highly influences the efficiency of an engine. When it comes to back pressure, mixer 3 has the most optimal features. Even though the pressure at front part of mixer 3 was low, the pressure at end part had a large low-pressure, creating a strong swirl.

- The largest value of maximum velocity distribution of the mixers was mixer 2 followed by mixer 3 and then mixer 1, respectively. The shape, angle, and plate size of the blades affected the flow velocity. Maximum velocity was approximately two times faster than the minimum velocity at each section.

- Lower RPM had a more even-uniformity distribution than a higher RPM. mixer 2 and mixer 3 had a stronger swirl at the end part of the mixer than mixer 1 which led to a drastic uniformity increase up to the 10cm point but then decreased and bounced back at around the 15cm point.
• Uniformity distribution reached 95% at around the 12~15cm point for mixer 1 and at around 22~25cm for mixer 2 and mixer 3.
• 95% of uniformity was measured at all points beyond 25cm. Regarding the results, it was concluded that mixer 3, which has the lowest back pressure, has the most optimal engine efficiency and can conform to the latest exhaust gas regulations.

References


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