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Analysis on Flow Characteristic According to the Shape Change of Mixer Blade in Urea-SCR System

[1]Namwook Kim, [1]Munseok Choe and [2]Dooseuk Choi
[1]Department of Mechanical Engineering,
[2]Mechanical & Automotive Engineering, Kongju National University, Korea

Abstract: The purpose of this study is to analyze the influence of mixer blade angle change in urea-SCR system on the system through post treatment technology that aims to reduce nitrogen oxide and optimize mixer shape. A model to analyze mixer and exhaust pipeline was made by using CATIA V5 to conduct flow analysis and then analysis was made by using ANSYS program. Water instead of urea was used for easy analysis. Variables in unit of 5° across a range from 0-45° were given in mixer blade angle from 1,000-4,000 rpm. Analysis showed that, the more mixer blade angle increased, the more uniform distribution of pressure and velocity was and the less back pressure at the front end in mixer was analysis of flow uniformity index showed that changed mixer blade angle lessened phenomena that flow uniformity index reduces in a section that swirl occurs compared to existing model and it increased gradually in a mixed section. It was ascertained that when changing mixer blade angle by 30, uniformity was high and back pressure was low which suggests that 30° model is the optimized level.

Key words: Mixer blade, uniformity index, back pressure, NOx, SCR, mixed

INTRODUCTION

Diesel automobiles are in the spotlight in the automobile industry because it is more cost effective than gasoline and it has high air fuel ratio due to high pressure combustion. Chae (2010) diesel automobiles produce less Carbon Dioxide (CO2), Carbon Monoxide (CO) and Hydrocarbon (HC) than gasoline engines but they produce more noise and vibration and produce a lot of Particulate Matter (PM) and Nitrogen Oxide (NOx) caused by high combustion temperature which led experts to study and develop various post treatment technologies (Won, 1997)

It is necessary to reduce PM and NOx which are harmful exhaust gases as restriction on exhaust gas such as Euro and Tier that are applied around the world, continues to be strengthened. In order to meet the restriction on exhaust gas emission, PM was reduced by over 90% through DPF (Diesel Particulate Filter) using filter and catalyst and NOx was reduced by using EGR (Exhaust Gas Recirculation), LNC (Lean NOx Catalyst), urea-SCR (Selective Catalytic Reduction) (Song, 2015). EGR among a broad range of technologies for reducing NOx, mixes a part of exhaust gas with air entering suction manifold and lowers oxygen concentration to reduce creation of NOx. EGR has been primarily used to meet the restriction on exhaust gas emission up to Euro 5 but it is expected that satisfying the restriction on NOx emission after Euro 6 using only EGR will be insufficient. Both LNC and urea-SCR systems use reducing agents to reduce Nox (Lee *et al*., 2012). The advantage of LNC is that, it can use existing fuels to reduce NOx but it is lower in NOx reduction efficiency than urea-SCR and it uses fuel as reducing agent leading fuel efficiency to be lessened which has made it less used recently (Rha and Oh, 2006).

Urea-SCR system reduces NOx to nitrogen and water which are harmless to human by spraying urea, ammonium solution into exhaust system (Song, 2014). Urea-SCR system is used most frequently because it has high NOx reduction efficiency under various temperature conditions (Han *et al*., 2008). However, urea-SCR system still has a lot of problems. One of the problems urea-SCR has is that liquid drop is distributed unevenly in exhaust pipe which obstructs smooth mixture with exhaust gas leading NOx reduction efficiency to be reduced and urea attached to inner wall on exhaust pipe causes durability to be lessened (Lee *et al*., 2010). As distribution of urea in exhaust pipe has been considered as important variable in urea-SCR system, there have been lots of attempts to

Corresponding Author: Dooseuk Choi, Mechanical & Automotive Engineering, Kongju National University, Korea

improve mixing efficiency such as changes in urea injector angle, position of mixer, opening and closing angles but studies on various mixer shapes are insufficient (Choe and Choi, 2016).

This study is to optimize mixer shapes by analyzing distribution of pressure and velocity and flow uniformity index in urea-SCR system according to mixer blade angle change using ANSYS, commercial program.

MATERIALS AND METHODS

Research model: Figure 1 shows a schematic diagram for exhaust system in diesel engine. PM contained in exhaust gas after combustion is reduced through DPF installed at the front end of exhaust system. NOx in exhaust pipe is reduced by urea sprayed from urea injector via. control unit with 5 bar being mixed with exhaust gas causing chemical reaction in SCR catalyst leading to NOx in exhaust pipe. This study conducted flow analysis for urea-SCR operation part among exhaust systems to check mixing efficiency of exhaust gas and urea according to mixer shape change.

Conditions and method of analysis: Figure 2 is a modeling of which exhaust system line and mixer shape are simplified to conduct flow analysis. The analysis was conducted by fixing mixer and urea injector to parts in exhaust gas flow line indicated as rectangular and circle. When conducting a study that aims to ascertain improvement in urea-SCR system performance by changing mixer blade angle from -5 to +5°, it was ascertained that the more blade angle increased, the better urea-SCR system performance was. In this study, mixer blade part indicated as a circle as shown in Fig. 2 was changed by 5° ranging from 0-45° to find optimum efficiency according to mixer blade angle change. Substance sprayed from injector was set as water not urea. The reason for which substance sprayed from injector was set as water was to make analysis easy because water accounts for seventy percent of Urea. Table 1 and 2 show detailed setting conditions. Mass flow according to the number of engine rotation was calculated by using Eq. 1:

$$M = \rho.R.\frac{v}{2} \quad (1)$$

Where:
M = Mass flow
ρ = Air density
R = Number of engine Rotation
V = Displacement Volume

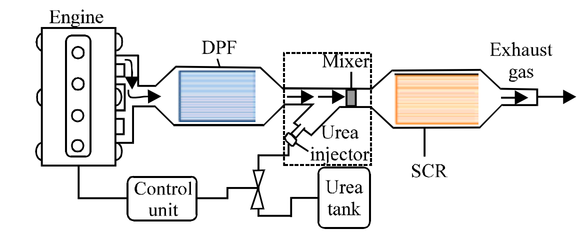

Fig. 1: Schematic of urea-SCR system

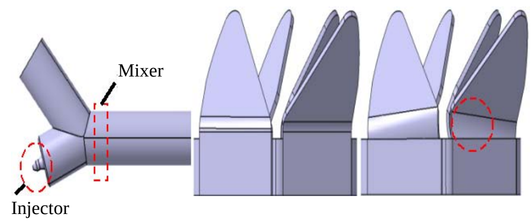

Fig. 2: Design of exhaust flow line and mixer

Table 1: Standard conditions

Items	Values
Mixer position (mm)	488 (From the rear end of exhaust line)
Injection angle	20°
Injection velocity (m/sec)	24
Injection number of nozzle	3 EA

Table 2: Essential conditionsitem

Items	values
Exhaust inlet mass flow (kg/sec)	0.04~0.16
Exhaust temperature (°C)	25
Mixer blade angle	0~45°
Injection material	H20

RESULTS AND DISCUSSION

A result of analyzing distribution of pressure: Figure 3 is a graph showing distribution of pressure at the central axis of exhaust pipe according to distance when changing mixer blade angle at 2,000 rpm. When analyzing flow from 1,000-4,000 rpm, it was ascertained that overall pressure value increased but there was no significant difference in distribution of pressure according to an increase in mixer blade and thus, only 2,000 rpm section which is used most on average was indicated. Analysis was conducted by dividing findings of analysis into area where backpressure is produced at the front end in mixer, area where mixing occurs after passing a mixer and area where stabilization is made after mixing. When analyzing distribution of pressure at the central axis of exhaust pipe, it was ascertained that the more blade angle increased, the less back pressure that occurs at the front end in mixer but pressure value at the center of exhaust pipe increased in stabilization area. It was ascertained that for rapid decrease in pressure in mixing section, reduction in

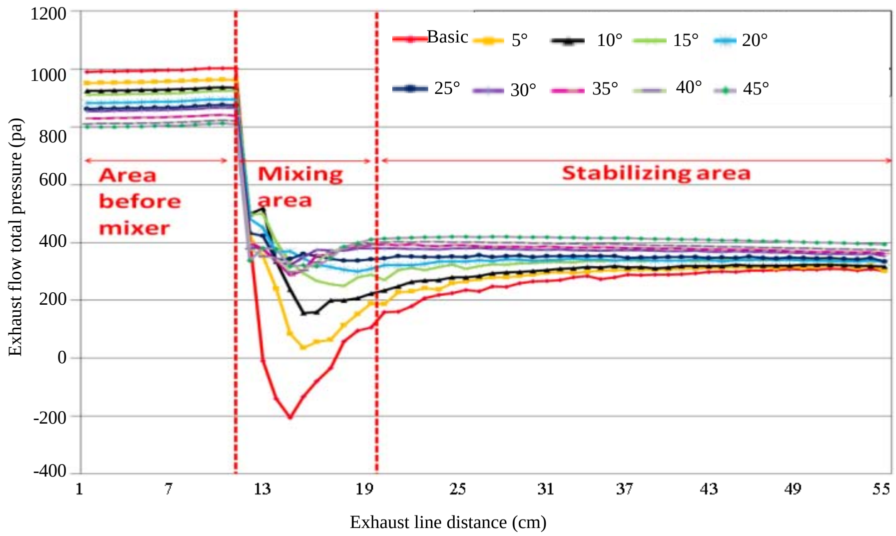

Fig. 3: Total pressure result of central exhaust line according to mixer blade angle change at 2,000 rpm

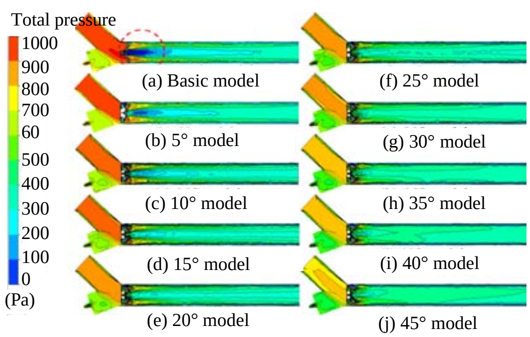

Fig. 4: Distribution of pressure at the center of the exhaust line according to mixer blade angle change at 2,000 rpm

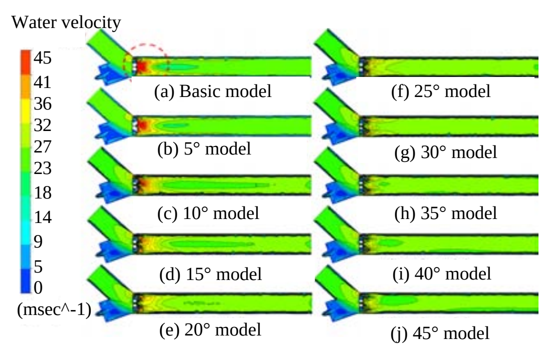

Fig. 5: Velocity distribution according to mixer blade angle change at 2000 rpm

pressure decreased until mixer blade angle changed up to 25° but there was no significant change when blade angle was 30° or higher.

It seems that a decrease in back pressure is caused due to evenly distribution of flow in overall exhaust pipe after passing a mixer as mixer blade angle increases, unlike existing models in which back pressure at the front end in a mixer rose as air that flowed in through entrance leaned too much towards the outside of exhaust pipe after it passed a mixer.

Figure 4 is a result showing pressure distribution throughout flow line when changing mixer blade angle at 2,000 rpm. For existing model, it was ascertained that pressure at the center of exhaust pipe indicated as a circle decreased sharply and value of pressure distribution shown at the center of exhaust line increased after it passed a mixer until mixer blade angle value reached 35° but value of pressure distribution at the center of exhaust line was equal to value of pressure distribution at the outside of exhaust line in 40° or higher model. It seems that the reason for above mentioned result was caused by concentration of flow at the center of exhaust pipe because shape of mixer blade got twisted towards the inside of exhaust pipe as mixer blade angle increased.

Result of analyzing velocity distribution: Figure 5 is the result of showing the velocity distribution by changing mixer blade angle at 2,000 rpm. For existing model, it was ascertained that value of velocity distribution at the center of exhaust pipe indicated as a circle after it passed a mixer was high. It was ascertained that overall velocity distribution in exhaust pipe was constant as value of velocity at the center of exhaust pipe was lowered until mixer blade angle changed up to 30° but value of velocity at the center increased starting from 35° or higher model.

(msec^-1)

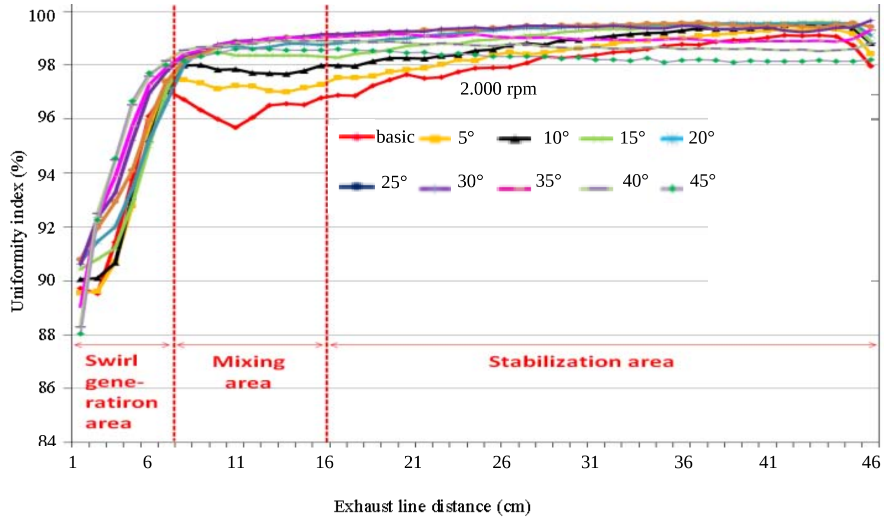

Fig. 6: Uniformity of mixer blade angle change

The reason for the above mentioned result seems to be caused by the flow being concentrated at the center of the exhaust pipe according to mixer blade angle change. It was ascertained that as mixer blade angle increased, overall velocity distribution throughout exhaust gas flow line was constant which suggests that water sprayed through injector will be distributed more evenly than existing models.

Flow uniformity index: Figure 6 is a result of flow uniformity index according to exhaust line distance when changing mixer blade angle up to 45° at the interval of 5° at 2,000 rpm. For a model that mixer blade angle changed up to 30°, it was ascertained that overall flow uniformity index increased by up to 2% compared to existing models and flow uniformity index increased stably in mixing section unlike existing models which flow uniformity index increased unstably in mixing section. It was ascertained that when changing mixer blade angle, flow uniformity index increased at a shorter distance but flow uniformity index decreased towards the back end starting from 35° model. It was ascertained that when changing mixer blade angle up to 45°, flow uniformity index decreased up to 98% in stabilization area.

It seems that the reason for above mentioned result was caused by concentration of flow at the center of exhaust pipe because shape of mixer blade got twisted towards the center of exhaust pipe as mixer blade angle changed up to 45° unlike existing models in which flow was concentrated towards the outside. The reason for which flow uniformity index in stabilization area starting from 35° became lower than that of existing models seems to be caused by more flow was concentrated towards the center of exhaust pipe than flow spread over the outside of exhaust pipe after it passed a mixer.

CONCLUSION

This study conducted analysis of flow by using ANSYS, commercial program to ascertain an influence of mixer blade angle change on mixing efficiency of reducing agents and exhaust gas in urea-SCR system. Findings of this study are as follows.

When changing mixer blade angle up to 45°, back pressure at the front end in mixer decreased up to 200 Pa which suggests that mixer blade angle change will improve engine efficiency. It was ascertained that the more mixer blade angle changed, the more constant value of velocity distribution was compared to existing models which suggests that, it prevents urea from being attached to inner wall of exhaust pipe leading to improvement in mixing efficiency of urea and exhaust gas. It was ascertained that the more mixer blade angle changed, the shorter swirl generation area was compared to existing models and flow uniformity index decreased again towards the back end in exhaust gas flow line starting from 35° model. When comparing back pressure at the front end in mixer that may have a negative influence on engine and flow uniformity index in exhaust gas flow line, it seems that increasing mixer blade angle up to 30° leads to optimum efficiency.

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