Design of Static Mixer To Improve The Uniformity Index In Urea SCR System

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Abstract- *Urea-Selective Catalytic Reduction is being developed as the most efficient method of reducing NOx emissions in the after-treatment devices of diesel engines, and recent studies have begun to mount the Urea-Selective Catalytic Reduction device for diesel passenger cars and light-duty vehicles. In the present study, The Uniformity Index of spray droplets in straight pipes with and without static mixers and the interaction between spray droplets and the blades of mixers are investigated by developing a computational fluid dynamic model. The effects of the mixer on the efficiency of urea-SCR System (i.e., NH_3 uniformity index) is investigated by predicting the transport phenomena in the urea-SCR system. The three dimensional Eulerian-Lagrangian CFD simulation for internal flow and spray characteristics in front of SCR is carried out by using ANSYS-Fluent.*

Keywords- SCR; Uniformity Index; Urea water solution, static mixer, ANSYS Fluent.

I. INTRODUCTION

It is well known that diesel engines generally have higher thermal efficiency and emits more pollutants such as nitric oxides (NO_x) and particular matter (PM) than gasoline engines. Therefore, in the Transportation industry, the reduction of emissions from diesel engines has been paid attention for both human health and the environment in the past decade. The Urea-SCR is most commonly used technique to minimize the amount of NOx in exhaust gas [1]. Urea-water solution is sprayed into the high temperature exhaust gas before the catalyst so that urea $CO(NH_2)_2$) ideally decomposes into NH_3, which is the reducing agent needed to covert NO_x to N_2 on the catalyst in three steps [2]. In SCR technology, the chemical reaction takes place at low temperature zone, and Ammonia is used as a reducing agent in Urea-SCR [3]. Numerical analysis using computational fluid dynamics will be an effective tool for predicting the transport phenomena and obtaining optimal design in exhaust system because of that it is mostly used to forecast the performance of Urea-SCR process [4]. when comparing simulation results and experimental results both are in close agreement. It is possible that in SCR system, the reduction rate of NOx can be predicted effectively with the help of simulations [5]. This paper investigates the performance of static mixer on SCR system.

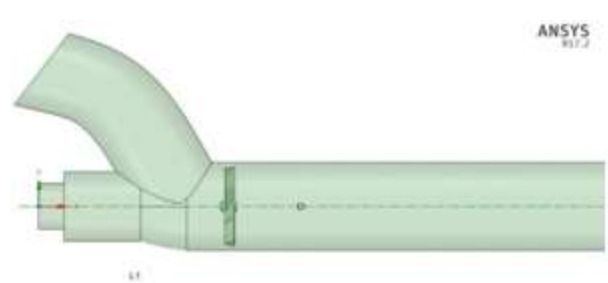
II. COMPUTATIONALMODEL

2.1 Geometric model of exhaust pipe

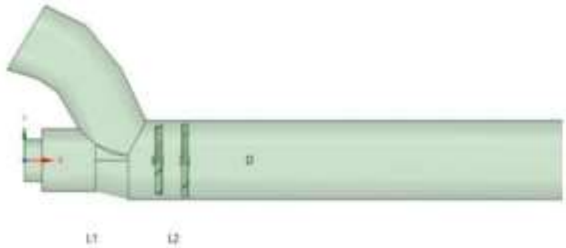
The pipes with one mixer, two mixers and no mixer were presented in Fig. 1.

The diameter of the pipe is 76 mm (D). The injector is positioned at the center of the pipe and located 73 mm away from the mixer (L1). For the system with one mixer, the mixer is positioned 150 mm downstream the injection. For the system with two mixers, the first mixer is positioned 150 mm downstream the injection, the second mixer is positioned 20 mm (L2) downstream the first mixer and installed in an opposite direction to generate higher turbulence intensity.

a)



b)



c)

Fig1.SCR pipe with a) no mixer b) one mixer c) two mixer

2.2 Geometric model of static mixer

The model of static mixer consists of eight pitched blades as shown in fig 2. Each blade has an inclination angle of 45^{o} with gas flow direction in order to increase turbulence. Each blade has a rectangle shape (33 mm long and 12 mm wide).

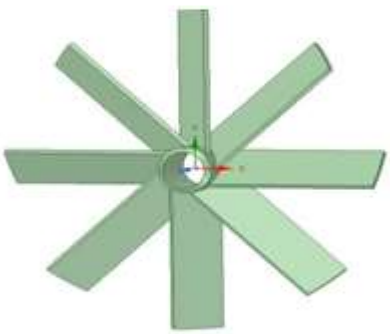


Fig2. CAD model of static mixer

2.3 Numerical Analysis

In the present work, the grid system for the urea-SCR system is constructed by Space Claim CAD file in Ansys workbench and the characteristics of heat and mass transfer are predicted numerically through a general purpose CFD software, ANSYS Fluent for Eulerian-Lagrangian CFD simulations. For mesh modeling, tetrahedral elements (No. of mesh: 368763) are used as shown in fig 3 and fig 4.

Fig3 mesh model of SCR pipe

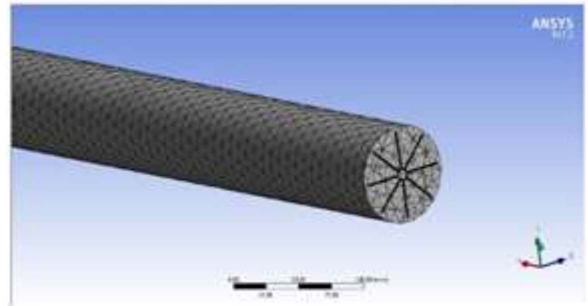


Fig 4 Mesh model of static mixer

Urea-water solution (UWS) contained solid phase urea is assumed to be a dispersed multi-phase flow so that its droplets are treated with Lagrangian particle tracking, which solves the equations of motion for parcels of droplets with adequateproperties. Each particle moves randomly and collides through a unique trajectory which is formed by interaction. In addition, particles are bounced and shattered at the wall of exhaust pipe. Phenomena of heat and mass transfer and phase change cause its size to change. Therefore, in the present work, numerical analysis for the exhaust gas with high temperature is carried out first in a continuous phase and then transport phenomena of UWS using a Lagrangian framework for a dispersed phase can be obtained. In this case, a carrier stream is adopted for an exhaust gas and a computational parcels concept in which the number of particles is probabilistically occupied within the finite parcels is used for UWS. As mentioned earlier, computational simulation has carried out by considering the atomization process and chemical reactions such as evaporation of water, thermolysis of urea, and hydrolysis of iso-cyanic acidin a Lagrangian framework. The exhaust gas is assumed to be air because the primary objective of this study is predicted the characteristic of UWSbehavior in the urea-SCR system. It enters into the system with a temperature of 300^{o}C at a flow rate of 39.6g/s and combined with UWS in the entrance region of the system. The flow rate and temperature of exhaust gas at the inlet region are used by considering the average load of NEDC mode. The UWS(urea: 32.5 wt%, water: 67.5 wt%) is horizontally injected into the exhaust pipe in front of the catalyst through three nozzles at the total flow rate of 0.262g/s. The nozzles have the same shape and size with diameter of 0.215mm. The pressure boundary condition is adopted at the exit region and no-slip boundary condition is used in all walls.

III. RESULTS AND DISCUSSION

3.1 Exhaust Pipe without Static Mixer

In exhaust pipe without static mixer condition the maximum uniformity index value is found as 0.87 and the minimum uniformity index value is 0.56.

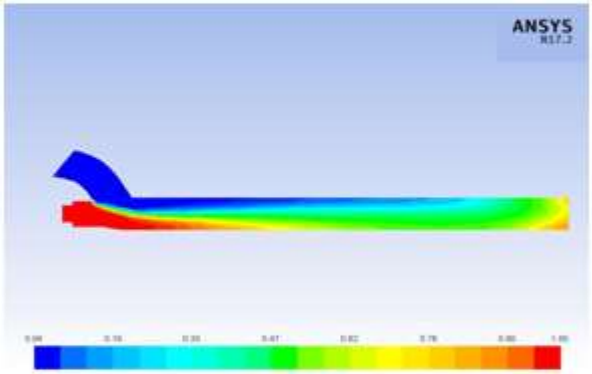


Fig 5 - Contours of uniformity index in XY plane

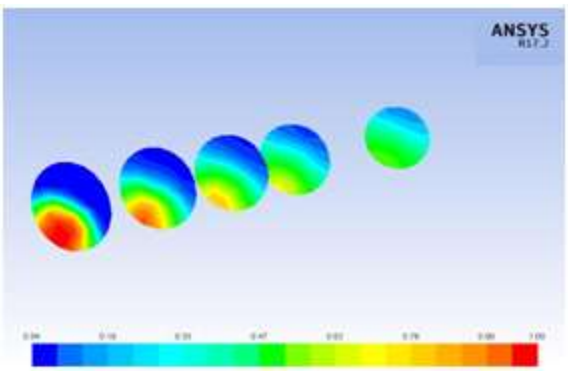


Fig 6 - Contours of uniformity index in several planes along the length of the pipe

The fig 5 shows the exhaust gas coming from the exhaust outlet and the ammonia coming from the ammonia inlet. Now both exhaust gas and ammonia are getting mixed at exhaust pipe and shows the contours of distribution of ammonia and exhaust gas in XY plane.

As shown in fig 6 the distribution of uniformity index of NH_3 (UI) according to the distance from the injector (0.2, 0.3, 0.4, 0.5 and 0.6 m). There are five planes which are created after the ammonia injection inlet, the first plane is created 200 mm from the injection point and other planes are created with 100 mm intervals.

The first plane which is located 0.2 m from injection inlet has the uniformity index of 0.56, after 0.1 m the second plane is located which has 0.67 likewise the uniformity at fifth plane is 0.87.

Kyoungyoo. [4] numerically studied the influence of mixer on the performance of urea-SCR system. He has found the uniformity index of 0.78 for the urea SCR system with no static mixer condition.

3.2 Exhaust Pipe with One Static Mixer

In exhaust pipe with one static mixer condition the maximum uniformity index value is 0.92 and the minimum uniformity index value is 0.71 is found.

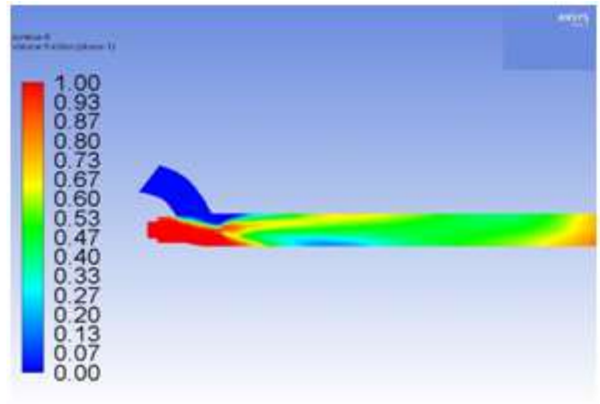


Fig 7 - Contours of uniformity index in xy plane

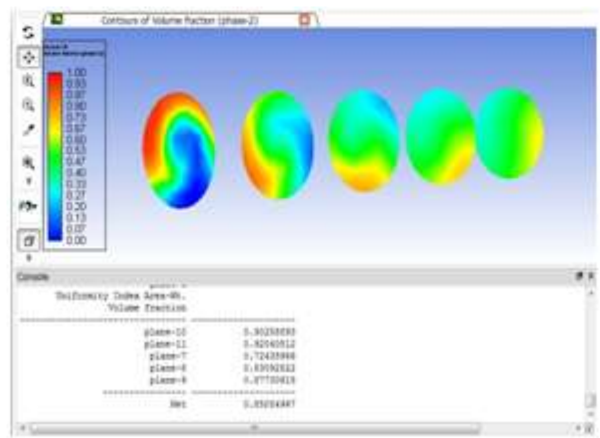


Fig 8 - Contours of uniformity index in several planes along the length of the pipe

The fig 7 shows the exhaust gas coming from the exhaust outlet and the ammonia coming from the ammonia inlet. The static mixer is located 0.15 m from the ammonia injection inlet. Now both exhaust gas and ammonia are come and contact with the static mixer and getting mixed because of turbulence created by the static mixer at exhaust pipe and shows the contours of distribution of ammonia and exhaust gas in XY plane.

As shown in fig 8 the distribution of uniformity index of NH_3 (UI) according to the distance from the injector (0.2, 0.3, 0.4, 0.5 and 0.6 m). There are five planes which are created after the ammonia injection inlet, the first plane is created 200 mm from the injection point and other planes are created with 100 mm intervals.

The first plane which is located 0.2 m from injection has uniformity index of 0.71, after 0.1 m the second plane is located which has 0.83 likewise the uniformity at fifth plane is 0.92. Kyoungyoo. [4] numerically studied the influence of mixer on the performance of urea-SCR system. He has found the uniformity index of 0.92 for the urea SCR system with one static mixer condition.

3.3 Exhaust Pipe with Two Static Mixers

In exhaust pipe with two static mixers condition the maximum uniformity index value is 0.94 and the minimum uniformity index value is 0.72 is found.

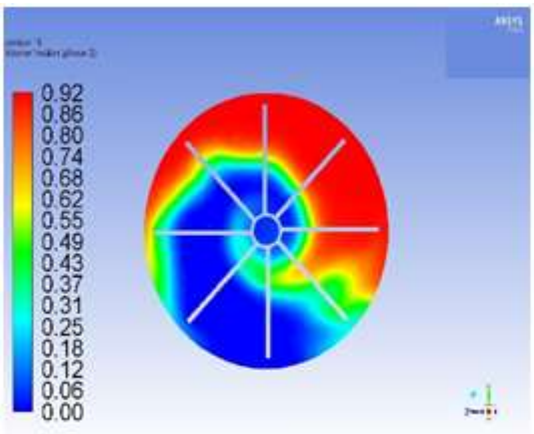


Fig 9Contours of uniformity index in xy plane

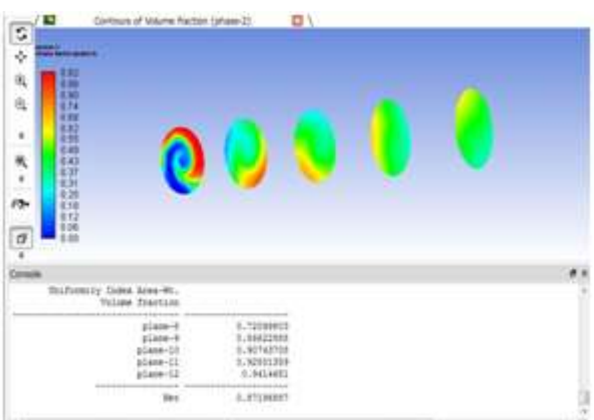


Fig 10Contours of uniformity index in several planes along the length of the pipe

The fig 9 shows the exhaust gas coming from the exhaust outlet and the ammonia coming from the ammonia inlet. Two static mixers are located 0.15 m and 0.17 m from the ammonia injection inlet. Now both exhaust gas and ammonia are come and contact with the static mixer one and getting mixed because of turbulence created by the static mixer one then it passes through static mixer two that creates more vortex flow and helps to increasing mixing at exhaust pipe and shows the contours of distribution of ammonia and exhaust gas with two static mixer in XY plane.

As shown in fig 10 the distribution of uniformity index of NH_3 (UI) according to the distance from the injector (0.2, 0.3, 0.4, 0.5 and 0.6 m). There are five planes which are created after the ammonia injection inlet, the first plane is created 200 mm from the injection point and other planes are created with 100 mm intervals.

The first plane which is located 0.2 m from injection has uniformity index of 0.72, after 0.1 m the second plane is located which has 0.86 likewise the fourth plane has UI value of 0.928 and the uniformity at fifth plane is 0.94, which is higher than the exhaust pipe with one static mixer condition.

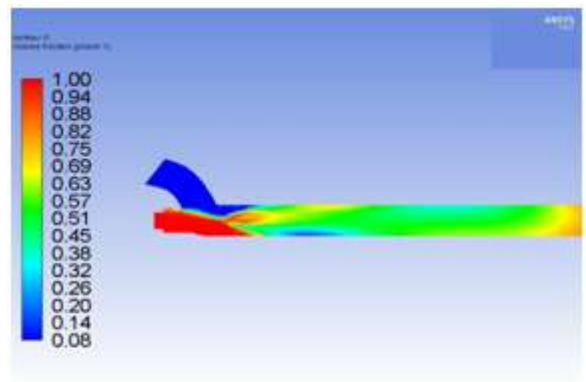


Fig 11Contours of uniformity index near the blades

As the above fig 11 shows the effect of static mixer in the downstream flow which indicates how the ammonia and exhaust gases are distributed at the area near to the static mixer blades and also indicates the turbulence intensity of two fluids.

3.4 Discussion of Results

The uniformity index for various cases such as without mixer condition, with one mixer condition and exhaust pipe with two static mixer condition has been tabulated for different distances from injector (Table 1) below.

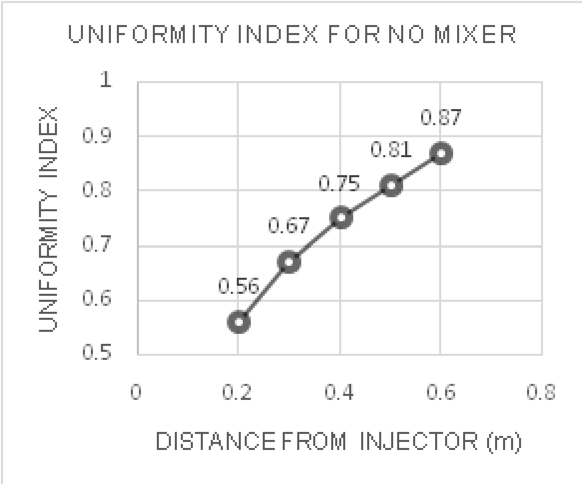


Fig12Uniformity of ammonia in the system without mixer

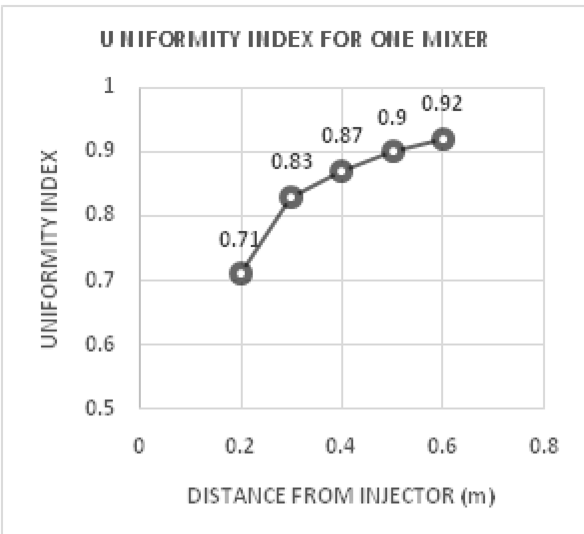


Fig 13Uniformity of ammonia in the system with one mixer

Fig12,13 and 14shows that the using of mixer significantly increases the uniformity index of NH_3 and urea conversion. When two mixers are used in the system, the uniformity index of NH_3 and urea conversion increase further more. In the system with one mixer and two mixers, at the plane located 0.4m downstream the injection, the uniformity index of NH_3 has a significant increase, achieving 0.87 and 0.9. However, for the system without a mixer, the uniformity index of NH_3 increase slowly within a large distance in the pipe. At the plane located at 0.6m away from injection, the uniformity index of NH_3 in the systems without mixers, with one and two mixers, achieves 0.87, 0.92 and 0.94. The higher turbulent intensity and swirling flow caused by the mixers enhance the mixing ability of NH_3 and gas exhaust.

For the system with two mixers, although the second mixer that installed in the opposite direction somehow cancel out the swirling flow, the increasing turbulent intensity has a great influence on the increase of the mixing ability of mixture gas.

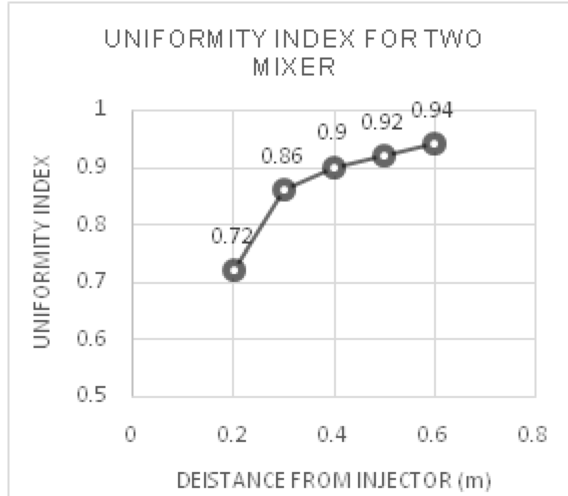


Fig 14Uniformity of ammonia in the system with two mixers

Fig 14 shows the plot of uniformity index for two static mixer condition at different distances from injection inlet, the first plane which is located 0.2 m from injection has uniformity index of 0.72, after 0.1 m the second plane is located which has 0.86 likewise the uniformity at fifth plane is 0.94.

Table 1 Uniformity Index Value for Various Cases

S.no		1	2	3	4	5
Distance from Injector (m)		0.2	0.3	0.4	0.5	0.6
Uniformity Index	No Static Mixer	0.56	0.67	0.75	0.81	0.87
	One Static Mixer	0.71	0.83	0.87	0.90	0.92
	Two Static Mixers	0.72	0.86	0.90	0.92	0.94

IV. CONCLUSION

In this present work, the design of static mixer and the influence of static mixer on the performance of urea-SCR system in diesel engine has been studied, which is the promising technologies for reducing the nitrogen oxides (NO_x) emission. general purpose CFD code of ANSYS FLUENT is used to predict the Three-dimensional transport phenomena in the exhaust pipe and a multi-phase flow are considered for Eulerian framework for exhaust gas and Lagrangian one for solid phase of urea-water-solution, respectively. From the results, it is suggested that the introduction of mixers will increases the mixing ability of exhaust gas with reducing agent was much faster. In an exhaust pipe without static mixer, the distribution of NH_3 is poor, while the uniformity of NH_3 for the system improves significantly increasing the number of mixers. As a result, the design and orientation of static mixer part plays a vital role in injection and mixing of ammonia with exhaust gas and to improve the performance of the SCR system.

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