

# A study effects of injection pressure and wall temperature on the mixing process of NO<sub>x</sub> and NH<sub>3</sub> in Selective Catalytic Reduction system

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# A study effects of injection pressure and wall temperature on the mixing process of NO<sub>x</sub> and NH<sub>3</sub> in Selective Catalytic Reduction system

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## Abstract

Diesel engines are commonly used for public transportation on-road and off-road applications. Growth production of the diesel engine is very significant from year to year. Nitride Oxide (NO<sub>x</sub>) from diesel engine was the one of the major sources of the air pollution. Selective Catalytic Reduction (SCR) has been successfully used to reduce NO<sub>x</sub> from diesel engine with chemical reaction from ammonia (NH<sub>3</sub>). The mixing reaction between NO<sub>x</sub> and NH<sub>3</sub> reaction can produce steam (H<sub>2</sub>O) and Nitrogen (N<sub>2</sub>). However, ammonia uniformity pattern usually not homogenization and the ammonia was difficult to mix with NO<sub>x</sub>. The constant air flows incomplete to assist the spray injector to spread NH<sub>3</sub> to all corners of SCR. The impact study of turbulent phenomena and standard k-epsilon Low-Reynolds Number model to mixing process in SCR system using STARCCM+. The simulation studies are conducted under different pressure (4 to 6 bars), injection rate (0.04 g/s) and temperature (338 K – 553 K) and the high pressure and high velocity magnitude creating turbulent swirl flow. The ammonia decomposition process and mixing process with NO<sub>x</sub> were investigated using box with optical access. The simulation and numerical study results validated using back pressure value and the distribution of NO<sub>x</sub> concentration value from the catalyst outlet. The wall temperature will increase the urea evaporation to generate ammonia and gas pressure will increase the mixing process and chemical process in SCR system. These reactions enable to optimize the SCR system technology which eventually able to reduce the NO<sub>x</sub> quantity from diesel engine.

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Keywords: diesel engine; wall temperature; wall impingement; urea water solution (UWS); urea injection; selective catalytic reduction (SCR).

## 1. Introduction

Diesel engines are commonly used for public transportation on-road and off-road applications. Growth production of the diesel engine is very significant year to year [1][2][3][4]. Some of the major advantages of diesel engine over another fuel engine are the higher durability and increased fuel efficiency. On the other hand, the main disadvantage is related to the exhaust emissions from the diesel combustion process. The emission of diesel engine is one of the major sources of the air pollution which need to be controlled by after-treatment system. Government has released a regulation for

automotive industry related to the exhaust gas emission to further reducing the nitrogen oxide emissions.

The emission rules has reach the pollution limit of the EURO VI and the US TIER 2 regulation [1][5][6]. The ammonia in the Selective Catalytic Reduction as the main solution to control specific emissions from engine. The technology of SCR used the injection of a urea liquid into the exhaust system. The hot temperature from exhaust makes Urea-water solution (UWS) evaporates and decomposes to be ammonia. Ammonia concentrate used as reducing nitrogen oxides (NO<sub>x</sub>) in the SCR system.

Many researchers study around the injector for spraying urea (NH<sub>3</sub>), gas temperature, and catalyst substrate in SCR system, but the ammonia still difficult to mix with NO<sub>x</sub>. Based on our previous

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study [7], it has been mentioned that the urea is difficult to evaporate and easily attached to the wall and making the solid deposit in the system. It is consistent to the study carried out by Hasan [8] which found the solid deposited effect to mixing process at SCR system.

The most important concept for mixing process is the turbulent air flow from the exhaust gas in SCR system. Exhaust air flow was assisting the spray injector to spread  $\text{NH}_3$  to all corners in SCR system. To solve that situation, this study presents a simulation and experiment study of the turbulent phenomena impact and the standard k-epsilon Low-Reynolds Number model to mixing process in SCR system using STARCCM+. To create turbulent in SCR system, this study uses pressure from exhaust gas and wall temperature from SCR system.

The simulations study based on the exhaust gas system with a high pressure to create turbulent swirl flow. The ammonia decomposition process and mixing process with  $\text{NO}_x$  were investigated using box with optical access. The data obtained from the optical box can assist identification of the actual condition in SCR system. The effects of wall impingement on deposit formation in diesel SCR system has been investigated the wall temperature (338 K) and (573 K). In the previous research carried out by Auvray [9], it was shown the temperature (473 K) and (598 K) can be used to analyze kinetic modeling on  $\text{NH}_3$  in SCR system.

Furthermore, our previous study [4] also used a high temperature of 536 K to study the ammonia uniformity in SCR system technology. A similar study from Smith [2], it has used a low temperature of 473 K and a high temperature of 608 K for analyzing the deposit formation reaction. Based on those investigations, the temperatures used in this system are 338 K for low wall temperature and 553 K for high wall temperature. The simulation and numerical study results validated using back pressure value and the distribution of  $\text{NO}_x$  concentration at the SCR system.

## II. Method and Experimental Setup

### A. Mathematical model

The numerical study with 3D simulation for understanding mixing process in the SCR system was shown with STARCCM+ software version 11.04. In other paper from Fischer *et al.* [10], compare the Reynolds-averaged k- $\epsilon$ -models [14] Reynolds-Stress-model (RSM) to accounting the anisotropic character of turbulence in the swirl flow. Fischer *et al.* used pipe with oval/flat crosses section for assist mixing process in the SCR system. The RSM describe the anisotropic turbulence between the primary swirl core and the outer secondary. This method is useful to understanding the TKE values in the pipe cross section and dissipation value in the swirl core. However, the RSM difficult to predict the highly turbulent reaction at the inner and outer swirl core.

Yi [11] has analyzed the ammonia homogenization from two different mixers with renormalize of Navier-Stokes equations (RNG) and

the k-epsilon model for turbulence study. The CFD model of their research simple SCR system installation. The straight pipe with urea injector and leading into catalyst. The urea injector is located at the wall with  $90^\circ$  angle relative to the main flow. Without a mixer system, the low quality of ammonia uniformity is resulted. The integrating a helix swirl mixer in the system leads the ammonia rise the good quality of uniformity.

This study was applying straight pipe and optical box with fully SCR system. The urea injector is located at top of optical box. That urea can release the UWS spray was from top to bottom. This observed is focus on the distribution of exhaust gas with pressure to get the turbulence quality without the mixer. The eddy viscosity from k-epsilon model equation, determined from a single turbulence length. The calculation of turbulent diffusion can achieve by the specified scale. Although in the real system, all motion scales will contribute to the turbulent diffusion.

The numerical computation with realizable k- $\epsilon$  model for resolved the viscous layers and viscous sublayer in the SCR system. These equation functions of wall treatment can be extended and solving the multiphase flow phenomena and motion of gasses from  $\text{NO}_x$  and ammonia wherein the gasses is characterized by properties that are aggregated over a large number of individual molecules [12][13]. Each particle in the system has associated with physical equation, such as density, velocity, vorticity and temperature. The vector quantity in the numerical properties assumed to be observable and hence there are 'streamlines' at the local velocity vector. Streamlines can never cross except at point sources or sinks of fluid. The transport equations for the Low-Reynolds Number with k-epsilon model equation can solving the computational domain:

$$\frac{d}{dt} \int_A \rho \epsilon dV + \int_A \rho \epsilon (v - v_g) \cdot da = \int_A \left( \mu + \frac{\mu_t}{\sigma_\epsilon} \right) \nabla \epsilon \cdot da + \int_V \frac{1}{T} [C_{\epsilon 1} (G_k + G_{nl} + C_{\epsilon 3} G_b) - C_{\epsilon 2} 2\rho(\epsilon - \epsilon_0) + \rho \gamma_y + S_\epsilon] dV \quad (1)$$

where  $S_k$  and  $S_\epsilon$  are specified source properties,  $\epsilon_0$  is the ambient turbulence value for turbulence decay counteracting,  $\rho$  is the source density, and  $G'$  is the additional product from source term that is given by:

$$G' = D f_2 \left( G_k + 2\mu \frac{k}{2} \right) \exp(-E R e^2) \quad (2)$$

where  $D$  is the distance to the nearest wall of the source terms,  $d$  is the distance to the wall,  $k$  is turbulent kinetic energy,  $\mu$  is dynamic viscosity, and  $f_2$  is a damping function that is defined as:

$$f_2 = 1 - C \exp(-R e_f^2) \quad (3)$$

where

$$R e = \frac{\sqrt{k} d}{\nu} \quad (4)$$

and

$$R e_t = \frac{k^2}{\epsilon \nu} \quad (5)$$

The coefficients  $C$  and  $E$  are used the default values of 0.3 and 0.00375. and the value for coefficient  $D$  in the system is:

$$D = \frac{C_{e2}}{C_{e1}} \approx 1.3 \quad (6)$$

However, direct numerical simulation (DNS) of low-Reynolds number channel flow suggests that better results are obtained with  $D = 1$ , which is the default value that is used in STARCCM+. DNS was presence of free stream turbulence, in accuracy computing method the  $D = 1$  was used for minimizing the error result from turbulence equation. The momentum coupling model for flow sections used the vertices scale. The turbulent viscosity  $\mu_t$  has relation to get the turbulent kinetic energy  $k$  and dissipation  $\varepsilon$  equation:

$$\mu_t \sim \frac{k^2}{\varepsilon} \quad (7)$$

With regards in the scalar transport model equation, a direct proportionality of turbulent diffusive momentum and scalar transfer is assumed. This method can explain the turbulent scalar diffusion is directly linked to the turbulence models viscosity prediction in the equation:

$$\rho \mu_j \gamma = - \frac{\mu_t}{Sc_t} \frac{\partial \gamma}{\partial x_j} \quad (8)$$

The constant equation to get the proportionality value is used the turbulent Schmidt number  $Sc_t$ . An underestimated turbulent viscosity value in the equation model can be stable by reducing the Schmidt number value (0.7 – 0.9). Throughout the following investigations by Wardana [7], the turbulent Schmidt number for Standard k-epsilon Low-Reynolds Number model used the default value of 1.0 for described in this literature review.

#### 1) Thermolysis and evaporation of UWS droplets

Despite numerous experimental studies have been conducted [4][14][15], theoretical understanding for the decomposition and evaporation of UWS and Adblue droplets are still not

fully investigated. A theoretical study [9][12] was implemented using STARCCM+ for simulation which then compared by experimental works to get the best accuracy. This method assumes a two process of the uws evaporation process until the uws droplet is composed just only urea. It uses spherical method for the evaporation and decomposition processes without using urea crystallization in the process.

Rapid mixing model is used to evaluate the dissolved urea on the evaporation process of urea water solution. Because this model can identify the high transport coefficients from liquid phase. The result can explain the homogeneous distribution temperature in the system, concentration particle value and fluid properties in the uws droplet [9]. The variation model in uws concentration droplet's can be evaluated by:

$$\frac{Y_u}{dt} = - \frac{m_{vap}}{m_d} Y_u \quad (9)$$

where  $m_d$  is a the mass of droplet particle,  $dY_u$  is urea concentration value and  $m_{vap}$  is a vapor value of mass flow in the system. The evaporation rates in this equation is calculated by the Abramzon-Sirignano model [12]. That model useful for low computational to observe the uws droplet particle and suitable predict the spray modeling [12]. The urea particle will easily melts at 400 K [12] and the Arrhenius model can describes that chemical kinetics reaction by:

$$\frac{Y_u}{dt} = - A_f S \exp \left( - \frac{E_a}{RT_d} \right) \quad (10)$$

where  $S$  is droplet surface area in the system,  $\mu$  is mass of urea value,  $A_f$  is the frequency factor [kg/(sm<sup>2</sup>)],  $R$  is the universal value,  $T$  is the droplet temperature for gas constant and  $E_a$  is the activation energy in the system.

#### 2) Urea water solution injection

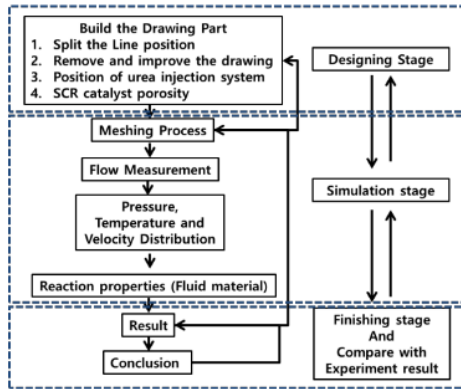


Figure 1. The flow chart of simulation process

Urea-water solution is the most commonly used for ammonia precursor in the SCR system because this material was safe for environment. The commercial name for UWS was Adblue, this aqueous was combination from 67.5 to 70 % deionized water and 30 to 32.5 % urea [12]. Gas emission from diesel engine usually produce more than 90 % of  $\text{NO}_x$  and 5 to 10 % of  $\text{NO}_2$ . That quantity dened from the diesel engine type.  $\text{NO}_2$  from diesel engine emission is useful for fast SCR reaction process. That chemical is produced from engine-emitted NO when oxidation reaction in the catalyst.

In order to describe the uws injection phenomena in the SCR systems, this study used mathematical description to explain all processes [3][9][12]:

Table 1. Engine specification

Engine parameter	Value
Displacement	498 $\text{cm}^3$
Bore	83 mm
Stroke	92 mm
Compression ratio	19.5
Con. rod length	145.8 mm
Crank radius	43.74 mm
Valve system	SOHC 4 valve
Fuel system	Electronic common rail

Table 2. Ammonia and exhaust injection

Parameter	Value
Exhaust inlet	10, 15, 20 m/s
Injector inlet	10, 15 m/s
Injection rate	0.04 g/s
Temperature	338 K – 553 K
Pressure	4, 5, 6 bar

- Interaction momentum between Exhaust gas and UWS droplets
- Thermolysis and Evaporation of UWS droplets
- Heat transfer from exhaust temperature to the wall and droplets. This section presents the mathematical basics model to implement the CFD modeling conduct the numerical simulations of SCR system by STRACCM+ software. The flowchart model for this simulation is shown in Figure 1.

## B. Experimental setup

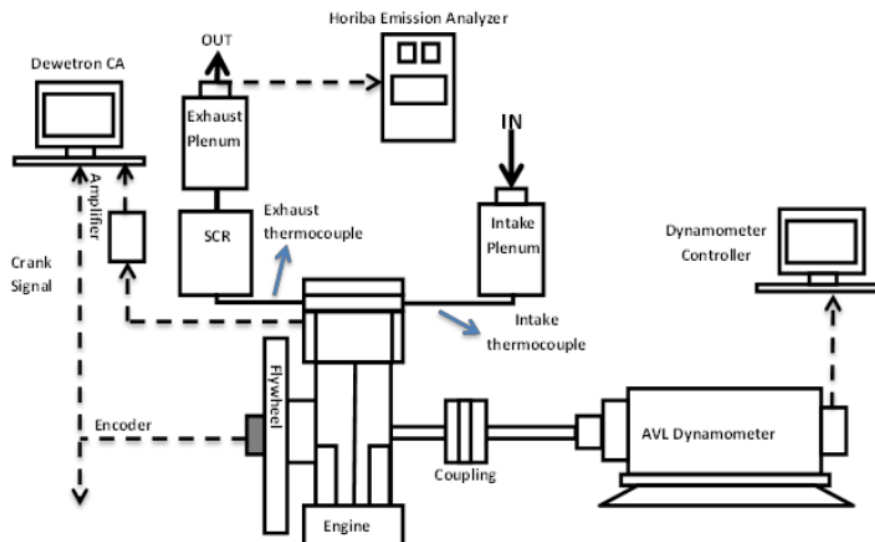


Figure 2. Schematic diagram of test engine and measurement setup

Table 3.  
Analyzed turbulence models and boundary conditions

Setup	Turbulence model	Boundary condition <sup>a</sup>
1	Standard Low Reynold	PI - VO
2	Number k-epsilon	

<sup>a</sup>V =Velocity; P =Pressure; I =Inlet; O =Outlet

The experiment condition used single cylinder with 498 cm<sup>3</sup> of displacement, naturally aspirated engine with 4-cycle, and 3 OHC 4 valves system to get the precision of engine test. The engine specification is shown in Table 1. The pressure at the exhaust was 4 to 6 bar [5][6][16] and leading into the optical box with straight pipe. A schematic diagram for the optical box test is shown in Figure 2.

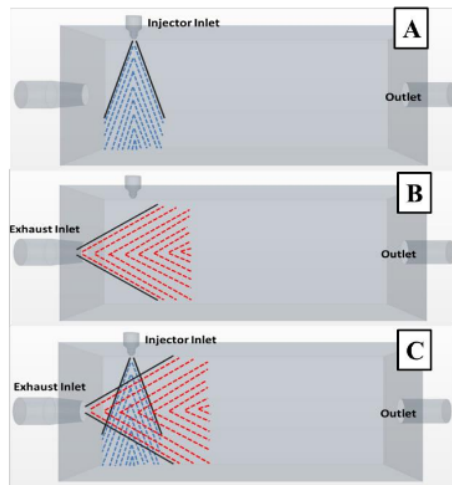


Figure 3. The measurement position of exhaust flow and ammonia injector spraying to the optical box: (a) Urea injection spray pattern; (b) Exhaust gas pattern; (c) Combination pattern from urea and exhaust gas

The pressure from UWS injector was ranging from 4 to 6 bar, ammonia injection rate (0.04 g/s) and exhaust temperature constant in 338 K – 553 K [5][6][16]. The injection specification is presented in Table 2. The optical box for measuring position and dimension was realized with silica glass. The positions and dimension were chosen to minimize the effect of gas flow in the system. The optical box gas flow distribution is shown in Figure 3. The mixing process between NO<sub>x</sub> and ammonia is observed in the optical box. The Horiba MEXA-7100DEGR is used to identify the emissions value from the system (hydrocarbon and NO<sub>x</sub>).

### C. Validation of simulation

To verify the Standard k-epsilon Low-Reynolds Number model simulation results from STARCCM+, the observation from ammonia uniformity at the SCR system have been carried out on the experiment test

[5][17]. The exhaust line directly connects with the SCR system. The Horiba MEXA-7100DEGR can determine the gas distribution and the hydrocarbon value from the catalyst outlet.

The Standard k-epsilon Low-Reynolds Number equation model is suitable for compute the convection flows. The situations to have a low-Reynolds number version of the Standard k-epsilon model, and Non-linear Constitutive Model as shown in Table 3.

The setups have two-equation models for the simulation of the measured ammonia uniformity. The error value for velocity magnitude model is the good agreement in order to observe the validated literature cases for k-epsilon model in the SCR system simulation [2][11]. By considering the complete process from UWS spray to the ammonia distribution in the optical box.

## III. Results and Discussions

### A. Exhaust simulation gas

Simulated distribution of the exhaust pressure streamlines in optical box system, as it has been predicted by STARCCM+. This simulation using the Standard k-epsilon Low-Reynolds Number model with prediction the effect of exhaust gas for ammonia decomposition phenomena can be calculated with the Schmidt number value. This energy value used to determine the turbulent viscosity and diffusion constant in the equation model. Besides that, this simulation model is implying the reduction of the anisotropic information for turbulent energy quantity at least for the scalar transport value.

Figure 4 shows the difference turbulence streamline and scalar distribution in the optical box. Gas flow in the optical box is the most important indicator to mix ammonia and NO<sub>x</sub>. This flow strongly influences the homogenization of ammonia vapor, even without a sufficient temperature from the ammonia injection. The amount pressure for mixing process of NO<sub>x</sub> and ammonia is shown in Figure 4(a). This picture described a pressure ratio between the lowest (4 bar) and the highest (6 bar). The color line explains the velocity value in the simulation. However, the quality of mixing process from Figure 4 was explained by the quantity of gas distribution in the simulation. It affects to the different movement of air in the optical box. When the higher pressure was used, this condition makes more diffuse flow of air generated and it was a good result for mixing ammonia and NO<sub>x</sub>. But instead when the smallest pressure is used, ammonia and NO<sub>x</sub> mixing is difficult to be created as air flow having difficulties to spread close to the wall and makes ammonia on the wall could not be parsed by air flow.

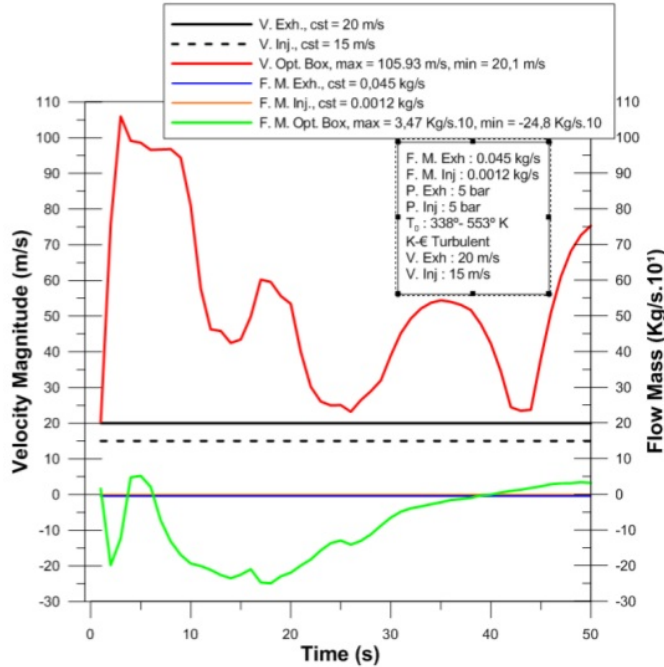


Figure 5. Velocity and flow mass effect at the optical box

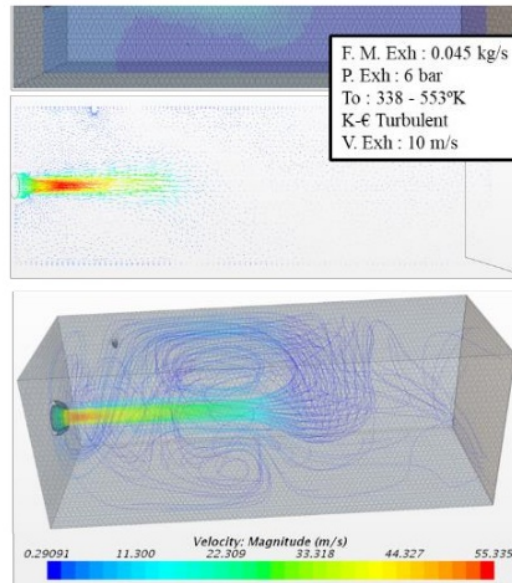


Figure 4. The difference turbulence streamline and scalar distribution in the optical box: (a) Exhaust turbulent phenomena and (b) Exhaust scalar phenomena

The air flow and pressure quantity also increasing the wall temperature value in the optical box. Figure 4(b) explains the temperature distribution in the simulation. Heating wall temperature propagates by flowing heat of exhaust gas from inlet to the outlet, more high gas flows from the exhausts more heat of the wall temperature, and it effects on the reduction ammonia droplet in the wall. This statement also has been explained in our previous study [7] which is observed the wall temperature value for predict the

urea injection process in SC<sub>2</sub> system. Figure 5 shows velocity magnitude quality. As can be seen from the figure, the constant exhaust flow mass value achieve at 0.045 kg/s, the maximal flow mass value achieve at 3.15 kg/s and minimal flow mass at -3.5 kg/s in the optical box. The free gas at the optical box makes flow mass in optical box unstable in first time. Flow mass is difficult to spared before free gas come out from the optical box. That case also happens in constant velocity magnitude. Maximal velocity

occurred due to the empty condition when the exhaust gas inside the optical box.

Figure 6 shows the pressure and force value. As can be seen from Figure 6, constant pressure occurred in 20 s after the exhaust come from the inlet. An empty condition in the optical box makes pressure decrease significantly to -102.15 bar. Exhaust gas occupies empty space in the optical box to encourage the free gas came out from outlet generate exhaust force gas and make pressure increase constantly after dedining. Maximal pressure happens in 13.2 bar and decrease after 12 s exhaust came from the inlet. That was contradicted with exhaust gas force value, when the exhaust gas pressure value decreases in optical box, exhaust gas forces increase until 19.78 kN and the force value decrease on -2.63 kN. Massive pressure was counted by volume of the optical box, the extent of affecting the increase and decrease of the exhaust gas pressure against time. With dimension of  $90 \times 30 \times 30 \text{ cm}^3$  of the optical box, the exhaust pressure needs 20 s for stabilizing into 1 bar. If using the small volume that can easily stable lowest than this

attached in the wall will settle and harden because the wall will heat up due to the creeping temperature of the engine heat. That reaction has an effect after long period application of SCR system in diesel engine.

The timing for spraying adblue in commercial diesel engine has been analyzed in exhaust simulation gas. For injector condition, the constant pressure and velocity value can set the turbulent flow in the system. The distribution gas and liquid was accounted, but it does not give insignificant impact from the spray characteristic in the flow field. That reaction occurring because the injector has low pressure and momentum for spraying the uws. Nonetheless, the flow field during the transient condition keep valid.

Figure 7 shows the difference turbulence streamline from UWS injector and exhaust gas in the optical box. This simulation shows that the  $\text{NO}_x$  and ammonia mixing can observed and analyzed in the optical box. Nonetheless, interdependencies from the liquid and gas phase with swirl fan mixing are avoided in this study. The ammonia vapor

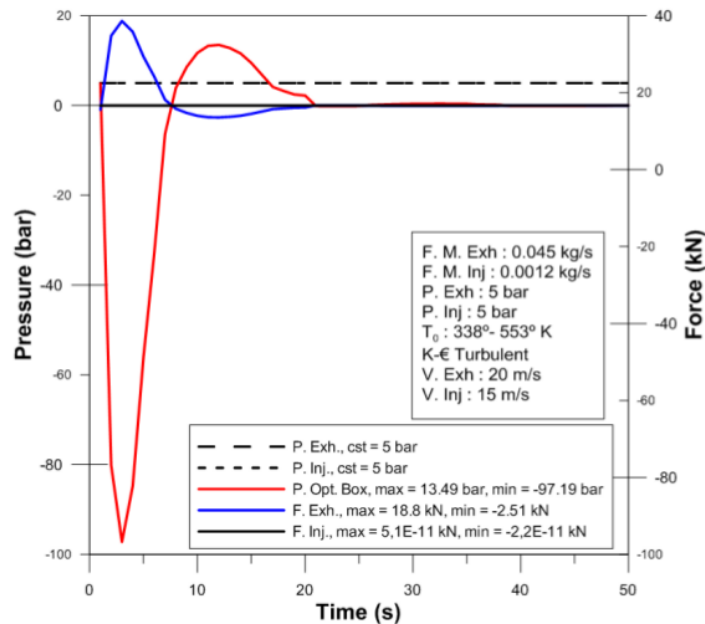


Figure 6. Pressure and force effect at the optical box

simulation.

### B. Injector effect on exhaust simulation gas

The distribution of the exhaust pressure can predict the streamline reaction in the optical box. At the first step of the exhaust inside the optical box, the pressure of exhaust was drop to -102.15 bar, that condition also happen in the real SCR in public vehicles. The amount of the pressure drop was depending on the size of the exhaust muffler (pipe and SCR system). When the SCR system has the pressure drop, the exhaust flow is difficult to spear the adblue from urea injector. The urea from adblue

concentrations got the averaged value by each computational cell when one-time injection duration. The resulting quasi-steady spatial for ammonia distributions value is observed on the cross sections as long as in the steady flow quantities. The simulation was plausible with visualizing and evaluates the ammonia homogenization process in the optical box.

The turbulent kinetic energy (TKE) is main parameter to determine turbulent viscosity and turbulent diffusion in this simulation[5]. Figure 8 shows the TKE value on the optical box. This TKE result got the maximum curves when the exhaust

gas come to the inlet (2.5 s). The gas flow distribution creating the steep velocity gradients by source of turbulence.

The kinetic energy structure divided into small-scale structures turbulence energy and transferred into dissipates rate of energy. The turbulent dissipation value in the system is shown in Figure 7. Though just using the k-epsilon model, the turbulent scheme showed very clearly. Beside that for detail result, it still need more deeply parameter using deference mathematic model.

### C. k-epsilon model validation

The ammonia uniformity in this study resulted that without a mixer system, the low quality of ammonia uniformity is resulted. The integrating a helix swirl mixer in the system leads the ammonia rise the good quality of uniformity. That result is explained on this validation purposes [10]. 2 results from this study will be compared to find the best values by the Standard k-epsilon Low-Reynolds Number model[10].

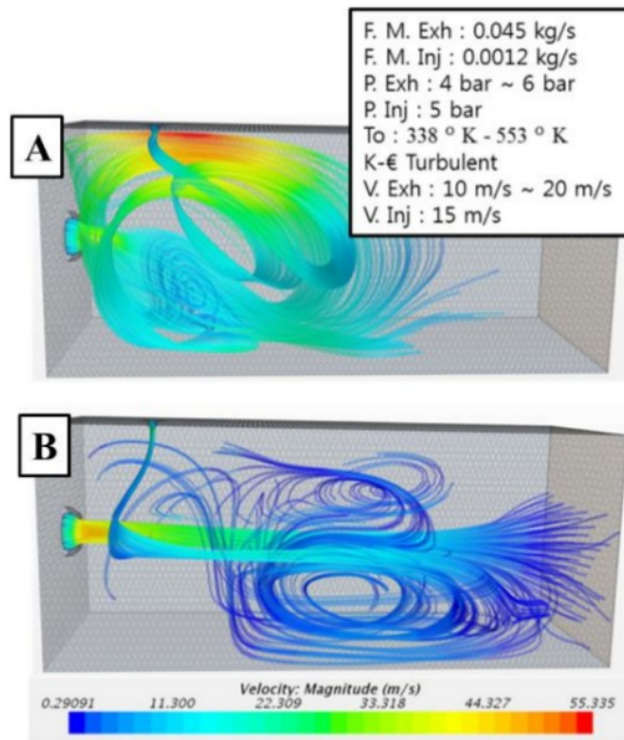


Figure 7. Exhaust and injector turbulent phenomena of (a) with low exhaust pressure and (b) with high exhaust pressure

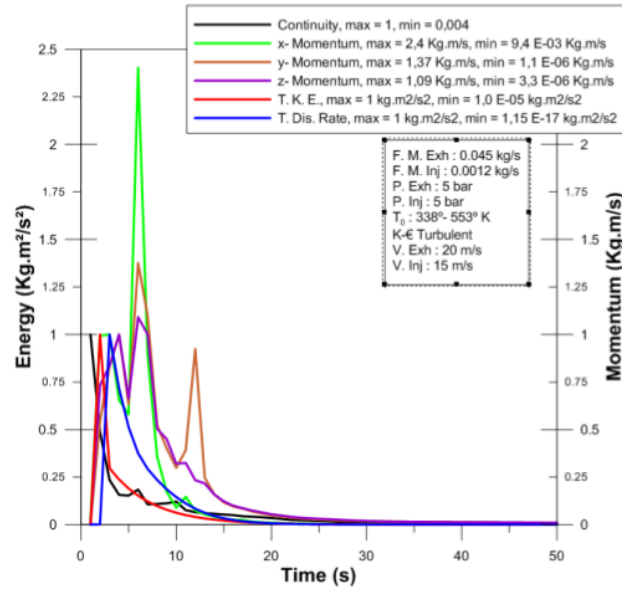


Figure 8. Turbulent kinetic energy (TKE) and turbulent dissipation rate (TDS) effect in optical box

Figure 9 shows the back pressure value between simulation and experiment in the optical box. This result explains the mass flow quantity from exhaust temperature and the amount of gas distribution. The Standard k-epsilon Low-Reynolds Number model has been calculated by heat temperature from exhaust inlet with the increasing wall temperature parameter. In that case, the temperature was the most decisive to mix ammonia and  $\text{NO}_x$ , besides the turbulence in the optical box. The back pressures value occurring at low volume condition can determine the magnitude of measurement precision. This parameter condition useful for computation in the validation discussion. The particular range in this simulation has offset value of approximately 1.0 bar and that value better 0.2 bar from RSM simulation condition. The measuring value for back pressure at high volume flow occurs when the measurement have the precise and reliable data [10]. That parameter can predict simulation with comparing the different turbulent model, which is expected to

get similarities and accuracy data measurement and simulation.

#### IV. Conclusion

Simulated distribution of the exhaust pressure streamlines in optical box system, as it has been predicted by STARCCM+. Gas flow in the optical box is the most important indicator to mix ammonia and  $\text{NO}_x$ . This flow strongly influences the homogenization of ammonia vapor, even without using a sufficient temperature from ammonia injection. Heating wall temperature propagates by flowing heat of exhaust gas from inlet to the outlet, more high gas flow from exhausts more heat the wall temperature, and the effect on the reduction ammonia droplet in the wall. The free gas at the optical box makes a mass flow in optical box unstable in first time. With dimension of  $90 \times 30 \times 30 \text{ cm}^3$  of the optical box, the exhaust pressure needs 20 s for stabilizing into 1 bar. If using the small volume that can easily stable lowest than this simulation. An empty condition in the optical box makes the pressure decrease so deeply until -102.15 bar when exhaust came from the inlet. Massive pressure was counted by volume of the optical box used, the extent of affecting the increase and decrease of the exhaust gas pressure against time. For injector condition, the constant pressure and velocity value can set the turbulent flow in the system. The distribution gas and liquid was accounted, but it does not give insignificant impact from the spray characteristic in the flow field. That reaction occurring because the injector has low pressure and momentum for spraying the uws. Nonetheless, the flow field during the transient condition keep valid. The turbulent kinetic energy (TKE) is main parameter to determine turbulent viscosity and turbulent diffusion in this simulation.

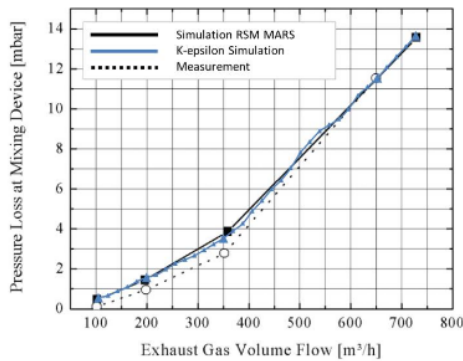


Figure 9. Comparison pressure loss at mixing device

In comparison TKE curves and TDS curve, the result has difference path to describe the turbulent energy based on the region section. The high momentum in this result can validate the strong energy from exhaust to increase the distribution of ammonia in the system. Although, this study has different parameter and CFD models with others study, this result can be a good knowledge for researcher to understand the mixing process of ammonia and NO<sub>x</sub> in SCR system technology.

## Acknowledgement

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## Nomenclature

CFD	: Computational Fluid Dynamic
MARS	: Monotone Advection and Reconstruction Scheme
NO <sub>x</sub>	: Nitrogen Oxide
K	: Kelvin temperature scale
SCR	: Selective Catalyst Reduction
TKE	: Turbulent Kinetic Energy
4)S	: Turbulent Dissipation Rate
UWS	: Urea Water Solution
RSM	: Reynolds Stress Model

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