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# A study of spray strategies on improvement of engine performance and emissions reduction characteristics in a DME fueled diesel engine

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ABSTRACT

This paper investigated the impact of injection angle and advance injection timing on combustion, emission, and performance characteristics in a dimethyl ether (DME) fueled compression ignition engine through experimentation on spray behaviors and the use of numerical methods. To achieve this aim, a visualization system and two injectors with different injection angles were used to analyze spray characteristics. The combustion, emission, and performance characteristics were analyzed by numerical methods using a detailed chemical kinetic DME oxidation model. Each of five injection angles and timings were selected to examine the effect of injection angle and timing. It was revealed that the injected spray with narrow injection angles was impinged on the bottom wall after the SOI of BTDC 60°, and most of the fuel spray and evaporation with the wide injection angles had a distribution at the crevice region when the injection timing was advanced. In addition, $NO_x$ emissions at the SOI of BTDC 20° and TDC had higher values, and the soot emission quantities were extremely small. The narrow injection angles had good performance at the advanced injection timing, and the injection timing over a range of BTDC 40–20° showed superiority in performance characteristics.



## 1. Introduction

It is widely known that diesel fuel is suitable for compression ignition (CI) engines due to its high cetane number and thermal efficiency. For this reason, diesel engines have been recently used in high-speed passenger cars, as well as large goods vehicles, trucks and vessels. The increasing usage of diesel-fueled vehicles has brought attention to environmental pollution issues arising from diesel engine exhaust emissions. Various investigations of spray and combustion technology have been conducted by researchers in order to decrease harmful emissions, such as nitrogen oxide ($NO_x$), particulate matter (P. M.), and unburned hydrocarbons (UHC) from diesel engines. Fuel injection strategies, including modifications of spray angle, timing, multiple injections, and injector location can have a tremendous impact on the combustion and emission characteristics during the fuel oxidation process. Therefore, many researchers have conducted experimental and numerical investigations of combustion and exhaust emission characteristics according to various injection strategies.

Venegas et al. [1] studied the effect of the three spray angles, 100°, 120°, and 148°, on the emission characteristics and combustion efficiency in a premixed charge compression ignition (PCCI) diesel engine. They report that high amounts of hydrocarbon (HC) and CO emissions at a spray angle of 120° with a BTDC of 50° at the start of the pulse and a spray angle of 100° are not fit for conventional diesel combustion. Kitasei et al. [2] performed an experimental and numerical investigation on the influence of different spray wall impingement angles on smoke emissions in a direct injection diesel engine. Their study revealed that the orthogonal and diagonal impingement cases have varied smoke characteristics due to the different main combustion regions according to the wall impingement point. An experimental investigation of the combustion processes according to various injection strategies in an optically accessible high-speed diesel engine with a narrow angle injector was conducted by Fang et al. [3]. From their observation results, the narrow angle injector offered more flexibility for combustion mode control than the original angle injector, and a multiple injection strategy led to combustion with lower exhaust emissions. Siewert [4] conducted parametric studies on the effect of combustion and emission characteristics, according to the spray angle and rail pressure in a diesel engine with a single cylinder. The wide spray angle using a conventional type caused increasing emissions as the injection

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timing advanced due to an increased amount of missed spray in the piston bowl.

Besides efforts to reduce the exhaust emissions in diesel engines by various injection strategies, many researchers have been developing technologies for alternative diesel engine fuels. Recently, dimethyl ether (DME) has been investigated, among many alternative fuels, as it has a high cetane number. DME also has the advantage of soot-free combustion due to the lack of bonding between two carbons. On the other hand, there are different fuel properties, such as lower viscosity and surface tension, as compared to diesel fuel.

Zhang et al. [5] conducted experimental and numerical investigations on the engine performance and emission characteristics in a small DME fueled diesel engine. They found that formaldehyde is a principal polluting compound of pollutant during the DME combustion process but that this decreased as the injection pressure increased or injection timing advanced. Kim et al. [6] studied the combustion and $NO_x$ emission characteristics in a DME fueled PCCI engine with different piston geometries. Their results revealed that the ignition timing advanced when the equivalence ratio increased and the engine with a narrow spray angle in modified piston geometry showed good performance at the advanced injection timing for PCCI combustion. Also, various other studies on DME fueled compression ignition engines, including spray, combustion, and emission characteristics, have been advanced by many researchers [7–10].

This paper investigates the influence of the spray angle and advanced injection timing on the combustion and emission characteristics in a DME fueled compression ignition engine. To achieve this purpose, spray characteristics according to injection timing were obtained using a visualization system. Based on the measured spray characteristics and model validation, the combustion, emission, and performance characteristics under various experimental parameters in a DME fueled CI engine were analyzed by using numerical methods with a KIVA-3 V code.

## 2. Experimental apparatus and procedures

### 2.1. Visualization for DME spray

A spray visualization system was used in order to analyze the effect of the injection angle on the DME spray behavior. This system was composed of a high-speed camera system, a light source with metal halide lamp, high pressure injection pump, and injection controller system, as illustrated in Fig. 1. In this experimental work, two test injectors with a different injection angle, such as 60° and 156°, were used. Because DME fuel exits in the gas phase at atmospheric pressure, the DME fuel tank was prepared in a pressurized status by a nitrogen gas. The pressurized DME fuel passed through high pressure pumps and a common-rail injection system. The energizing duration of the injector was controlled by the solenoid current of the injector driver. The injection quantity was fixed at 8 mg. The injected DME spray was visualized by a high-speed camera with two metal halide lamps. The ambient gas density in the high pressure chamber was adjusted by the nitrogen gas. The ambient gas density was changed from 6.9 kg/m$^3$ to 24.1 kg/m$^3$. The shutter signal of the high-speed camera and the injection signal of the test injector were synchronized by the digital pulse generator. The obtained DME spray images were stored and analyzed by computer with an image grabber and an image analysis program.

**Table 1**
Test engine specifications.

| Single cylinder diesel engine | |
|---|---|
| Engine type | DI diesel engine with common-rail injection system |
| Bore × stroke | 75.5 × 84.5 mm |
| Displacement volume | 373.3 cm$^3$ |
| Compression ratio | 17.8:1 |
| Piston shape | Re-entrant type |
| Injector specification | Six holes with 0.128 mm of hole size |
| Injection angle | 156° |
| The number of valves | 2 Valves for intake air<br>2 Valves for exhaust gas |
| Intake valve close timing (IVC) | BTDC 128° |
| Exhaust valve open timing (EVO) | ATDC 172° |

### 2.2. DME fueled engine for model validation

For the experimental validation, a single cylinder DME fueled diesel engine with a common-rail injection system was used. This four valve test engine had a compression ratio of 17.8 and a re-entrant type of piston head shape. The bore and stroke sizes of piston were 75.5 mm and 84.5 mm, respectively. In addition, the hole size and injection angle of high pressure diesel injector with six holes were 0.128 mm and 156°. Detailed engine specifications are listed in Table 1. Experimental results including combustion pressure and heat release rate were obtained from the direct injection single cylinder diesel engine with the common-rail injection system for validation of the calculated results on the DME combustion.

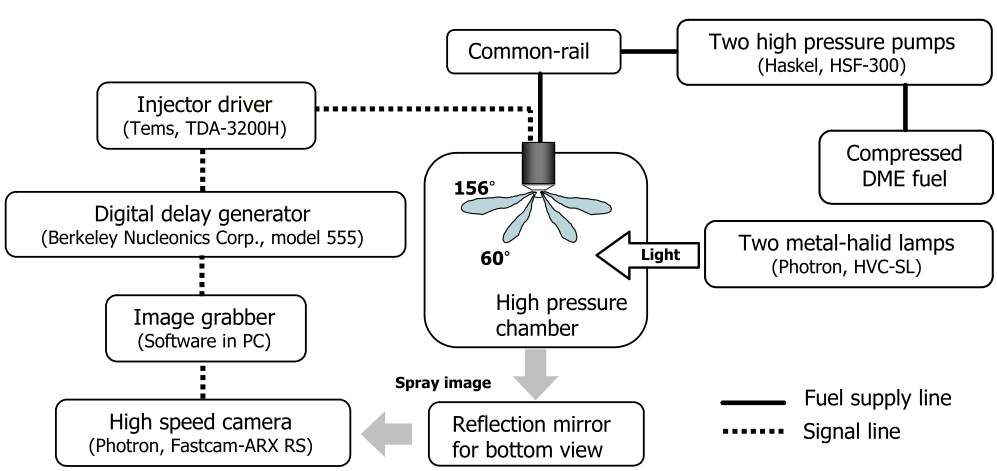


**Fig. 1.** Visualization system for DME spray behaviors.