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Effect of nano air-bubbles mixed into gas oil on common-rail diesel engine

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ABSTRACT

The nano air-bubbles mixed into gas oil are used for the energy saving and environmental load reduction of diesel engine. The nano air-bubbles were mixed into the fuel line continually by a super miniature ejector-type mixer (outer diameter: 20 mm, length: 34 mm) which can make nano and micro sizes. After the micro air-bubbles were separated with the nano air-bubbles in a mixing tank, diesel engine performance test with a common-rail injection system was experimented. The results showed that 3% reduction in break means specific fuel consumption, 1% rise in charging efficiency and a slight reduction in the density of exhaust smoke etc. These were caused by mixing the nano air-bubbles into gas oil. It is confirmed that the nano air-bubbles had advanced and activated combustion by a physical and chemical action.

1. Introduction

Recently, improvement in fuel efficiency of vehicles has been drastically required due to the aggravation of problems of the environment and energy, such as global warming, tight oil demand, etc. The demand for diesel passenger cars that are fuel-efficient and emit less greenhouse gases has increased centering around west Europe, where the sales share accounted for more than 56% in 2011 [1]. Meanwhile, in order to cope with the emission control regulations becoming more severe, the increase in the after treatment cost of gases emitted from diesel engines has become a large task. One of its solutions is a fuel pretreatment, that is to say fuel reforming.

Conventionally, various studies are being done on fuel additives to improve diesel combustion and decrease harmful emissions. In-cylinder strategy to reduce local temperatures and consequently the NOx production rate is the injection of water in emulsion with the fuel [2–16]. Most engine experiments and numerical studies using water emulsion fuel technique show that the NOx reduction is accompanied with a large reduction of PM and soot emissions. At a given fuel injection rate, the use of WDE leads to an increase of the total injected mass, of which a consequence is an increase of the mixing rate between fuel and air, thus reducing local fuel–air ratios and consequently PM production [3,10,12]. Author et al. have proceeded with research on simultaneous reductions of fuel consumption and poisonous exhaust gases by mixing gas oil with air-bubbles micronized using air as a means of fuel improvement [17–20]. As a result, the fuel consumption was reduced by 2–14% and reductions of exhaust smoke and NOx were also confirmed, by mixing the gas oil with micronized bubbles, or nano bubbles, to the extent where stable driving is possible without air entrainment in the engine.

As the diesel engine which was used in this research was a jerk fuel injection type, it is unknown whether the gas oil mixed with nano air-bubbles favorably affects the common-rail injection system that is most commonly used now.

Therefore, in this research, a new common-rail injection system was introduced and its effect on the high pressurization of gas oil mixed with nano air-bubbles was discussed experimentally.

2. A summary of micro and nano air-bubbles mixed into gas oil

Practical applications of micro and nano bubble technology have recently become to attract people's great concerns in wide variety of areas in advanced and conventional science and technologies, such as energy conversion and heat removal devices, diagnosis by

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ultrasound echo due to micro and nano bubble collapse, drug delivery systems, cleaning and sterilization by shock waves due to the collapse of high-pressure micro and nano bubbles, production of ozone water, mining using physical absorption at gas–liquid interfaces, purification and improvement of oil-contaminated soil and polluted water by air supply (sea, lake, river etc), absorption of carbon dioxide gas, fish culture, etc [21].

Fig. 1 shows (a) photograph of the device and (b) internal structure of an ejector-type micro and nano air bubble mixture device. The size of this mixture device was 20 mm in outer diameter and 34 mm in length, and the material was brass [22]. The left side of the figure is the inlet for fuel (hereafter referred to as gas oil) and the right side is the outlet of the gas oil mixed with nano air-bubbles.

The mechanism of mixing nano air-bubbles by this mixture device is as follows: 1) It injects the gas oil pressurized by a pump at a high speed using an injection effect or a nozzle, selfprimed air by the negative pressure generated in the neighborhood of the outlet, and form a film-like gas–liquid interface. 2) The absorbed air is separated and bubbled by the separation, turbulent mixing and shearing action of the gas oil. 3) The air-bubbles are further refined by the separation area formed in the sudden expansion region.

This is a method to prompt the atomization of the gas oil spray by mixing nano air-bubbles into gas oil as nano air-bubbles [18], and accelerate the combustion by increasing the amounts of dissolved oxygen and ions [18–20]. As the size of the nano air-bubble mixture device of this method is extremely compact, it is possible to retrofit it to existent diesel engines.

When air-bubbles of the macro or micro-size entered in fuel, a fuel injection pump and a nozzle caused an air entrainment and used only air-bubbles of the nanosize here to become unstable in an engine.

3. Experimental setup

3.1. Experimental apparatus

Fig. 2 shows the schematics of the experimental apparatus used in this experiment, Fig. 3 shows a photograph of its appearance, and Table 1 shows the test engine specifications. The engine load and rotation speed of this experimental apparatus can be controlled from a PC by software for the dynamometer (FC-design Co. Ltd. DA50-UW [23]). Vital engine factors, such as fuel consumption and intake air mass, can be directly obtained and stored by PC.

A commercially available Yanmar Diesel NFD150-E remodeled into a common-rail fuel injection system was used as the test engine (Table 1). As for the test fuels, ordinary gas oil (JIS No.2 gas oil, Table 2, hereafter referred to as control) and gas oil mixed with nano air-bubbles were separately used through a three-way valve fixed in a part of the fuel pipe. In order for the effect of the amount of mixed nano air-bubbles to be measured, two devices, nano air-bubble mixture device I and mixture device II, were fixed on the line of the gas oil mixed with nano air-bubbles.

Fuel flow rate was measured by a 213 type of Max Machinery Inc, smoke in exhaust gas by an opacimeter (light transmission type smoke meter, MEXA-600SW of HORIBA), O_2 concentration by LM-1 of Grid, and noise by a CEM DT-8851 noise meter. In addition, the noise meter was put in the distance of 1 m from engine side, and the setting assumed a properties (a weighted sound pressure level).

3.2. In-line type nano air-bubbles mixture device

In this experiment, two In-line type nano air-bubble mixture devices were fixed on the line supplying gas oil from the fuel tank to the engine. Fig. 4 shows a photograph of the mixture device. For the purpose of measuring the amount of nano air-bubbles mixed into the gas oil, two mixture devices were used.

The gas oil that flowed from the fuel tank and was pressurized by the nano air-bubble mixture device I selfprimes the air at the ejector part, which is sent to a mixing tank installed on the fuel line, as shown in Fig. 5. The ultra fine bubbles formed in this mixture device include micro bubbles and nano bubbles. Therefore, after the bubbles of micro-size were separated at the mixing tank, the gas oil mixed with nano bubbles is supplied to the engine. The gas oil mixed with ultra fine bubbles is referred to as “nano bubble gas oil” hereafter in this research. When the fluid level in the mixing tank rises and switches on a liquid level indicator, the flow is switched to the circulation line of the mixing tank. With this circulation, the efficiency of mixing nano bubbles is raised by increasing the number passing through the injector part. Mixture device II plays the role to raise the amount of bubbles mixed into the gas oil by circulating the gas oil in the mixing tank.

The amount of dissolved oxygen in the mixing tank was measured by a DO meter B-507 for organic solvent of Iijima Electronics Corporation.

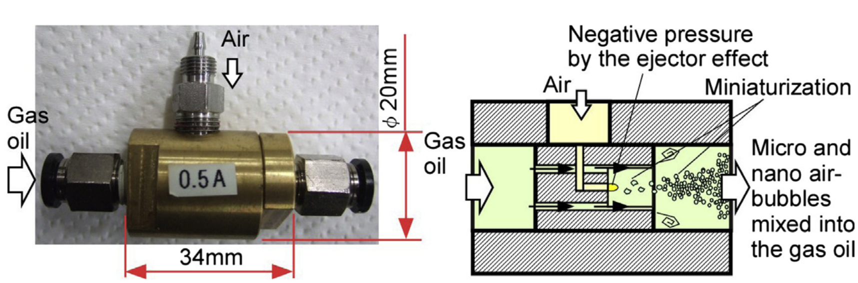
3.3. Common-rail type fuel injection system

Fig. 6 shows a photograph of the common-rail fuel injection system. This system was assembled with commercially available components. Table 3 shows the main specifications of the common-rail fuel injection system (FC-design Co. Ltd., Fi-CMR [23]). This system has the ability of multiple injections up to 7 point injections at the maximum injection pressure of 200 MPa.

3.4. Experimental method

A partial load experiment was conducted at a constant rate of 2000 rpm. The total performance of the engine, the smoke in exhaust gas and remaining O_2 were measured, when the brake mean effective pressure of atmospheric correction is 200 ~ 550 kPa.

The time of fuel injection was set as a single point injection 17° before top dead center, which was the rating before the engine was modified to a common-rail type, and the injection pressure was



(a) Appearance photograph (b) Internal structure

Fig. 1. Ejector-type micro and nano air-bubbles mixture device.