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Study of the generated density of cavitation inside diesel nozzle using different fuels and nozzles

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ABSTRACT

A comparative study using different fuels and nozzles has been conducted focusing on the generated density of cavitation inside diesel nozzle. In this paper a visualization experiment has been carried out and the new parameters are presented to compare the effect of the injection conditions (including injection pressure, the spray angle of nozzle, the length–diameter ratio of nozzle orifice and the fuel type) on the generated density of cavitation. The research results indicate that the generated density of cavitation is sensitive to the change of injection conditions. The generated density increases about 10% for every 10 MPa in injection pressure. The generated density increases with the increase of nozzle spray angle and with the decrease of length–diameter ratio. The cavitation appears early and changes fast by using the fuel with lower viscosity and higher saturated vapor pressure. The generated density of cavitation increases with the increase of saturated vapor pressure and decreases with the increase of viscosity.

1. Introduction

Over the years, many designers and researchers are continuously trying to improve the diesel engine performance to satisfy both the customer demands and the legislation requirements concerning pollutant emissions. Nowadays several different ways are followed to achieve these purposes: (a) the redefinition of the combustion process; Torregrosa et al. [1] investigated the engine performance, emissions and combustion noise with PCCI combustion process. Gan et al. [2] reviewed the implementation of HCCI combustion, the governing factors in HCCI operations and the effect of design and operating parameters on HCCI diesel emissions, (b) the use of multiple injection strategies; Thurnheer et al. [3] have done an experiment study to clarify the effects of different injection strategies on the performance of a heavy-duty diesel engine. Suh et al. [4] investigated the effect of multiple injection strategies on the spray and emissions fueling with dimethyl ether (DME), (c) the use of alternative fuels; Ozsezen [5] investigated the performance, combustion and injection characteristics of a DI diesel engine fueled with canola oil methyl ester and waste palm oil methyl esters. Qi [6] carried out an experimental study on the combustion characteristics and performance of a DI engine using biodiesel/diesel blends, (d) the after treatment technology of diesel engine emission, etc. Although these ways were taken to fulfill the customer demands and the legislation requirements, the injection nozzle in a diesel engine is always an important unit which affects the spray and atomization, and even affects the combustion process and the pollutant emissions. And nowadays the multi-orifice injector that was used in the diesel engine is also applied in the gasoline Direct-Injection-Spark-Ignition (DISI) engines [7].

The cavitation inside the diesel injector has already been observed by Bergwerk for more than 50 years [8]. Since then, the researchers had studied extensively the cavitation and its effects on the fuel injection, spray and atomization. It is well-known that the appearance of cavitation inside the injector has a negative impact on the fuel injection. For example, the cavitation would lead to a drop in the discharge coefficient and the cavitation erosion which occur at the wall of nozzle orifice. But many investigation results also indicated that it has a positive effect on the spray and atomization and the mixing process. As early as in 1995, Soteriou et al. [9] had revealed the relationship between cavitation and the spray abnormality, hydraulic flip, and between cavitation and atomization. Recently, the positive effect of cavitation has also been confirmed by Desantes et al. [10] through a special visualized technique. And it has been found that there were a noticeable increment of spray cone angle and spray contour irregularities as the cavitation bubbles appeared at the orifice outlet. Payri et al. [11] found that the cavitation would lead to an increment of the spray cone angle and the hole outlet velocity increases when the

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cavitation appeared. Mohan et al. [12] investigated the effect of internal nozzle flow and thermo-physical properties on spray characteristics using different biodiesel fuels. So it has been widely studied in recent decades. There are two main methods for studying the cavitation inside the nozzle: the numerical simulation method based on the Computational Fluid Dynamics (CFD) and the visualization experimental method based on the high-speed photography technology. In the numerical simulations studies, Shervani-Tabar et al. [13] had studied numerically the effects of cavitation on quality and spray characteristics like penetration length, SMD and distribution of fuel. Battistoni and Grimaldi [14] also made a comparative study on the cavitation inside nozzle and spray characteristics with diesel fuel and biodiesel fuels. Molina et al. [15] researched the influence of geometry of orifices on the inner nozzle flow and cavitation development using 5 different nozzles. Salvador et al. [16] had researched the influence of the needle lift and backpressure on the internal flow and cavitation by CFD using the RANS method. Meanwhile, they also used another method, the LES method, to study the cavitation and its interaction with the turbulence developed [17]. And in the visualization experiment researches, different structure nozzles have been developed with optical materials such as quartz and polymathic methacrylate. Suh and Lee [18] investigated the cavitation and the atomization characteristics using 2D square nozzles with the nozzle widths of 2 mm and 5 mm and the nozzle lengths of 9 mm and 13.5 mm. Sou et al. [19] examined the effects of cavitation in a nozzle on liquid jet atomization using a 2D rectangle nozzle which the $W \times L$ of nozzle is 4 mm × 1 mm and the length of nozzle is 16 mm. Zhong et al. [20] carried out an experimental study on the cavitation with different enlarged nozzle orifice diameters from 0.96 mm to 2.66 mm under a low injection pressure. Oda et al. [21] experimentally analyzed the effect of cavitation on spray primary atomization using a large-scaled VCO diesel injector with nozzle orifice diameter of 2 mm. Arcoumanis et al. [22] made an investigation on the cavitation with a real-size diesel nozzle orifice diameter of 0.176 mm under the injection pressure from 2.75 MPa to 21 MPa. Badock et al. [23] investigated the effects of cavitation phenomena with a real-size nozzle orifice diameter of 0.2 mm under the higher injection pressure from 15 MPa to 60 MPa. An investigation was conducted by Mitroglou et al. [24] on the cavitation inside the nozzle using a real-size six cylindrical orifice nozzle with the orifice diameter of 0.16 mm. In these experimental studies, the influences of different factors on cavitation and spray, such as nozzle geometry size (including nozzle form, orifice diameter and orifice length), injection pressure and orifice outlet pressure, were researched. In addition, the effect of fuel temperature on the cavitation and spray formation has been researched by Aleiferis et al. [25] using the hydrocarbon fuels and alcohols. The effects of physical properties of fuel on the cavitation have also been researched by Payri et al. [26] using different fuels (including n-heptane, n-decane, n-dodecane and commercial diesel). Furthermore, Payri et al. [27] have also carried out an experimental study for comparing the effects of the different fuels (diesel fuel and gasoline) on the mass flow rate, momentum flux and spray visualization in non-reactive conditions with a conventional common rail system with a multi-hole injector and two different nozzle designs. Desantes and Payri [28] have presented an experimental comparison of three biodiesel blends on injection rate shape, spray force, spray tip penetration and cone angle.

In previous experimental studies, the cavitation phenomenon inside nozzle was investigated directly through the photographs which were obtained from the visualization experiments. Most of results were natural and vague. There is a lack of quantitative analysis of cavitation level under different injection conditions. Therefore, the purpose of this work is to make a fixed quantity contrast analysis for the cavitation inside nozzle using different fuels and nozzles. For this purpose, firstly, the photographs of flow inside nozzle were obtained from a visualization experiment. And then two parameters, named the average volume fraction of cavitation (φ_{cav}) and the total average volume fraction of cavitation (φ_{total}), are defined by using the digital image processing technology and the light scattering theory based on the flow photograph. And finally, a comparative study using different fuels and nozzles has been conducted focusing on the effects of injection conditions (including injection pressure, the spray angle of nozzle, the length–diameter rate (L/D) of nozzle and the fuel property) on the cavitation by using these new parameters.

2. Experiment equipment and methodology

2.1. Experimental visualization equipment

The experimental visualization setup developed for this paper includes three parts: the fuel injection system, the optical imaging system and the flash control system (as Fig. 1). The fuel injection system is composed of a fuel injection pump test board which to drive a high pressure pump and a high pressure common rail fuel injection system which was manufactured by Delphi named Multec DCR1400. And a control program named Visu98 was applied to control the injection pressure and the fuel injection quantity. The optically imaging system includes a Canon EOS 500D CCD Camera and a long focal distance microscope which can magnify the subject to 25 times. The image of flow inside nozzle which including the nozzle and Sac with a resolution of 4752 × 3168 pixels can be shot using the optically imaging system. The flash control system includes a white light flash, a self-made

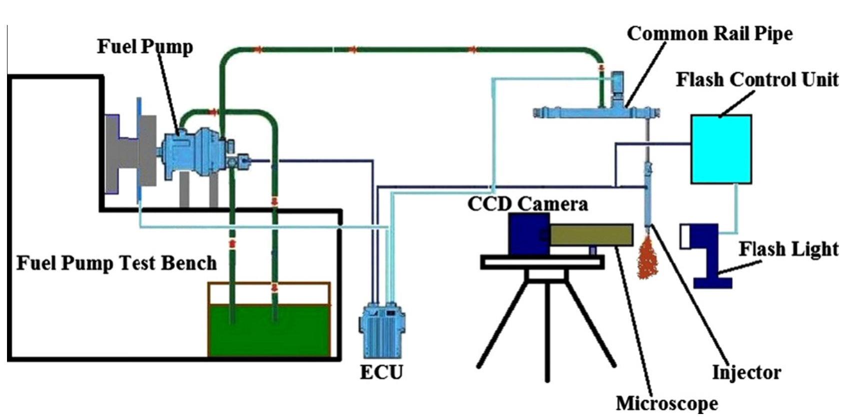

Fig. 1. Schematic of experimental visualization setup.