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Hydraulic characterization of diesel engine single-hole injectors

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HIGHLIGHTS

- 5 cylindrical nozzles and 5 convergent ECN nozzles have been measured.
- Convergent nozzles do not present cavitation.
- n-Dodecane injects less than diesel because of its lower density.
- Spray momentum is not affected by cavitation.
- Higher injection for the convergent nozzles despite the smaller diameter.

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ABSTRACT

Due to world trend on the emission regulations and greater demand of fuel economy, the research on advanced diesel injector designs is a key factor for the next generation diesel engines. For that reason, it is well established that understanding the effects of the nozzle geometry on the spray development, fuel–air mixing, combustion and pollutants formation is of crucial importance to achieve these goals. In the present research, the influence of the injector nozzle geometry on the internal flow characteristics is studied. For this purpose, ten single-hole diesel injectors differing in the orifices degree of conicity (five cylindrical, five conical) but with similar nozzle flow capacity have been characterized geometrically (measurements of nozzle outlet section) and hydraulically. The mass flow and momentum flux rates have been measured for a wide range of experimental conditions. Special attention is given to study the cavitation phenomenon since the cylindrically-shaped nozzle orifices are expected to propitiate cavitation due to abrupt changes in flow direction. The study has been carried out with two different fuels: n-dodecane and commercial diesel, thereby the effect of the fuel properties is also analyzed. The results show that the measured nozzle outlet diameters are higher than the nominal specification for both nozzle types. As expected, the onset of cavitation on the cylindrical nozzles has been identified causing a reduction on the injected mass for all tested conditions. The effective diameter for the cylindrical nozzles have been found to be around 175 μm (geometrical diameter ≈212 μm) and around 185 μm (geometrical diameter ≈191 μm) for the conical ones. Finally, the higher density of diesel with respect to n-dodecane have resulted on mass flow rates around 8% over the n-dodecane values for the same test conditions.

1. Introduction

In order to develop computational models to predict the combustion process in diesel engines, deep knowledge of the injection process and the spray development in the combustion chamber is required to reduce uncertainties and therefore improve the accuracy of the predictive methods [1].

With a view to promoting international collaboration among experimental and computational researchers within the engine combustion field, the Engine Combustion Network (ECN) [2] was created, addressing the research to reference test conditions and identifying priorities for future researches. Hardware and operating conditions with same specification and tightly controlled boundary conditions (e.g. "Spray A": 900 K, 60 bar, 22.8 kg/m^3, 15% oxygen [3,4]) have been used to develop highly leveraged data sets appropriate to engines [5].

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Nomenclature

ET	energizing time (electric command sent to the solenoid injector)	C_v	velocity coefficient
k-factor	nozzle orifice conicity factor	p_b	back pressure
Re	Reynolds number	p_i	fuel injection pressure
C_a	area coefficient	u_{eff}	effective injection velocity
C_d	orifice discharge coefficient		

The present paper is divided into six sections, starting with this introduction. After that, the new ECN injectors used for the study are presented followed by a summary of the physical properties of the fuels employed. Information regarding the experimental setup is given in Section 4 and the obtained results are presented and discussed in Sections 5 and 6.

2. ECN Spray C and Spray D nozzles

Regarding the injectors used for this study, the ECN group has recently acquired ten large-nozzle single-hole diesel injectors from Bosch. The solenoid-activated injector specifications pertain to modern advanced injection systems with 2200 bar nominal pressure rating (2500 bar capable).

The injectors incorporate an axial single-hole nozzle to facilitate optical diagnostics of the spray [6]. As can be seen in Table 1, ECN group has classified the ten injectors in "Spray C" or "Spray D", according to similar nominal parameters of their respective nozzles.

The five "Spray C" nozzles have a nominal outlet diameter of 0.2 mm. The orifice is cylindrical (*k*-factor equal to zero) with 5% of hydro-grinding to relatively smooth the contours of the orifice (see Fig. 1).

With respect to the five "Spray D" nozzles, these have a nominal outlet diameter of 0.186 mm. The orifice is conical with a *k*-factor of 1.5. Similarly, hydro-grinding has been performed to get a nominal $C_d = 0.86$ at the specified flow number. The use of convergent nozzles is justified precisely because the convergence of the holes will prevent the onset of the cavitation phenomenon [7]. Moreover, in recent years, engine manufacturers are opting for this type of nozzles instead of cavitating nozzles with cylindrical holes [8].

3. Fuel characterization

In order to perform rate of injection measurements (ROI) via injection rate discharge curve indicator (IRDCI), the speed of sound through the fluid at the operating temperature and pressure conditions has to be known [9]. Additionally, the density and viscosity at the orifice exit conditions are required to calculate the mass flow rate and Reynolds number. For those reasons, the fuels employed for the tests need to be completely characterized to assure the reliability of the results.

At first instance, the fuel employed for the tests has been n-dodecane. It is a fluorescence-free diagnostics fuel chosen by the ECN working group in order to enable a complete specification of the chemical and physical properties of the fuel [10].

Secondly, with the aim of simulating the real environment where the injectors operate, commercial diesel fuel is used in the comparison (in Spain share of biodiesel in commercial diesel fuel is variable with an average of 1.5% [11]). An analysis of the physical properties that are of interest for this study has been performed at CMT for the diesel fuel used in the experiments.

The first test consisted on the determination of the kinematic viscosity of the fuel.

The second parameter used in the calculations of the variables derived from the ROI measurements is fuel density. The standard methodology to obtain the density curve of a fuel, and the one used in this report, is explained in [12].

The effects of temperature on fuel density and viscosity obtained are shown in Fig. 2.

Table 1
Nominal specification of the ECN large-nozzle single-hole diesel injectors [2].

	Specifications for Spray C and D of the Engine Combustion Network	
	Spray C	Spray D
Common rail fuel injector	Bosch 3-22	Bosch 3-22
Injector nominal diameter	200 μm	186 μm
k-factor	*k* = 0	*k* = 1.5
Nozzle shaping	5% hydroerosion	Hidroerosion to $C_d = 0.86$
Flow with 10 MPa pressure drop	200 cm^3/min	228 cm^3/min
Number of holes	1 (single hole)	1 (single hole)

4. Experimental setup

The injection system that has been implemented for the study consists of commercially available components, namely a high pressure volumetric pump driven by an electric motor and a common-rail coupled with a pressure sensor to ultimately determine the discharge pressure. The system is capable of delivering fuel up to 250 MPa.

The rail has a volume of 22 cm^3 and is connected to the injector through a tube with a length of 20 cm and an internal diameter of 3 mm. The injector driver signal is constituted of a current pulse that rises up to 25 A for 0.1 ms, remains at 15 A for 0.45 ms as initial hold, and ends with 11 A as final hold. A constant voltage of 27 V is supplied to the solenoid.

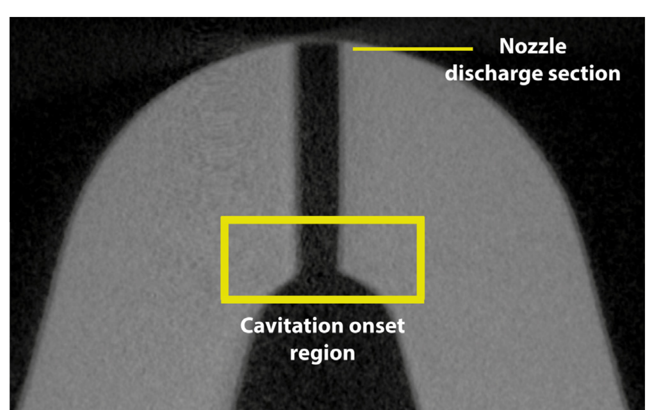

Fig. 1. X-ray tomography of a Spray C nozzle indicating the region where the boundary layer separation occurs [2].