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Experimental and numerical analysis of a high-pressure outwardly opening hollow cone spray injector for automotive engines

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ABSTRACT

The manuscript describes the characterization of a novel outwardly opening pintle-type injector, characterized by a Hollow Cone Nozzle (HCN), as a possible solution for ultra-low emission high-efficiency DI diesel and GDICI engines. In its prototypal version, the injector is capable of generating the hollow cone spray at relatively high injection pressure with a very precise fuel metering.

The study concerns some experimental and numerical activities aimed at the analysis of the spray generated by the HCN. A commercial supplier provided the prototypal version of the injector with a dedicated piezoelectric actuation system and a proper choice of geometrical design parameters. The experimental characteristics of the HCN concept (in terms of spray pattern and spatial penetration) were analyzed in a constant volume vessel. The OpenFOAM® libraries, in the lib-ICE version of the code, were employed for the simulation of the spray dynamics after a first validation phase based on the experimental data.

Results show a typical spray structure and the overall fluid-dynamics of the outwardly nozzle with a finely atomized spray, circumferentially well distributed, but displaying a reduced tip penetration. These characteristics appear very interesting, being well suited for the application of strategic spray concepts, to be coupled with dedicated combustion chamber designs both for CI and GDICI engines development.

1. Introduction

Combustion quality in modern diesel engines strictly depends on the efficiency of the air-fuel mixing, and in turn, on the quality of spray atomization process. As well known, air-fuel mixing is strongly influenced by injection pressure, geometry of the nozzle and the hydraulic characteristics of the injector.

Some characteristics are essential for a modern diesel Common Rail (CR) Fuel Injection System (FIS) in order to assure a satisfying spray quality. In particular, some of the fundamental requirements are the possibility of using very high injection pressures (P_{inj}), multiple and very near injections and high rate of the opening and closure nozzle lift. The current CR FIS reaches a maximum value of 200–220 MPa of P_{inj}, while systems up to 300 MPa are coming on the market [1,2].

Spray concepts alternative to the conventional Multi-Hole Nozzles (MHN) could be considered as solutions to the extremely high P_{inj} increase to assure a high and faster fuel-air mixing in the piston bowl, with the final target of increasing the fuel efficiency and reducing pollutant emissions at engines' exhaust.

At the same time, swirl supported combustion systems usually employed in diesel engines configurations do not help reducing heat transfer while, in principle, quiescent combustion systems could reduce the wall heat transfer through the piston, bowl and liner walls [3,4]. However, the hypothesis of reducing heat transfer losses via the reduction of swirl motion could be theoretically considered only leaving the well-assessed MHN configuration that needs swirl motion for an appropriate spray atomization level. Only proper solutions for nozzle configurations, intrinsically capable of producing a finely atomized spray homogeneously

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Abbreviations: ALMR, Adaptive Local Mesh Refinement; C_d, discharge coefficient; CI, Compression Ignition; CR, Common Rail; DDM, Discrete Droplet Model; ET, Energizing Time; FIS, Fuel Injection System; GDI, Gasoline Direct Injection; GDICI, Gasoline Direct Injection Compression Ignition; HCN, Hollow Cone Nozzle; ICE, Internal Combustion Engine; KH, Kelvin Helmholtz; MHN, Multi-Hole Nozzle; PECU, Programmable Electronic Control Unit; PM, Particulate Matter; RT, Rayleigh Taylor; SMD, Sauter Mean Diameter; TP, tip penetration.

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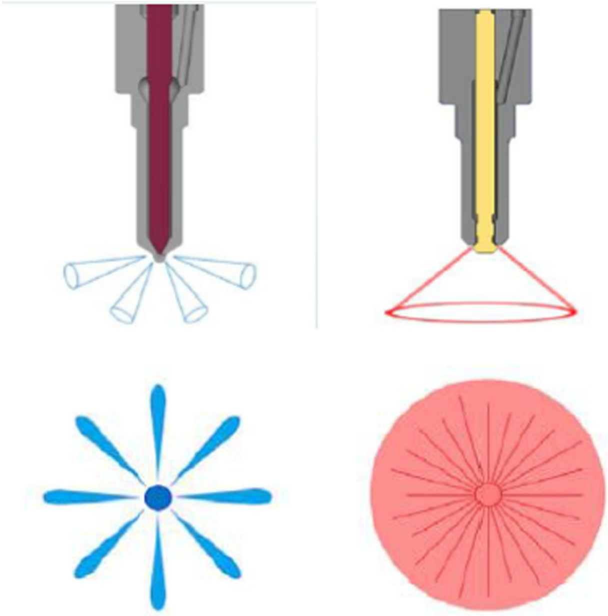

Fig. 1. Spray pattern comparison between the HCN (right) and MHN (left).

Fig. 2. Schematic view of geometrical features of HCN (left) compared with a conventional MHN (right).

Table 1
Energizing timings for the investigated injection strategies.

Qinj/Pinj	30 MPa	80 MPa	120 MPa
1 mm^3/shot	280 μs	200 μs	140 μs
10 mm^3/shot	500 μs	390 μs	340 μs
30 mm^3/shot	920 μs	660 μs	560 μs
60 mm^3/shot	1560 μs	1050 μs	900 μs

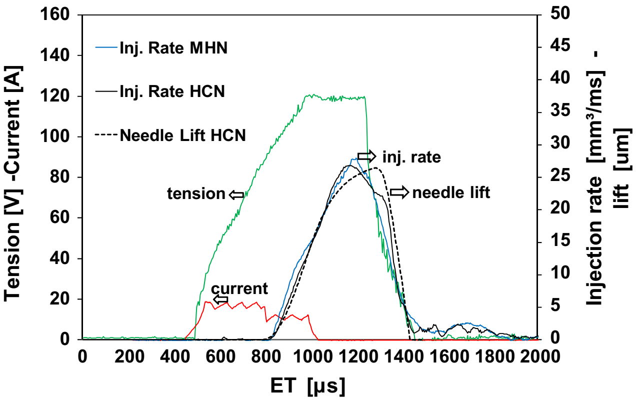

Fig. 3. Main functional characteristics of the HCN injector in terms of voltage command, needle lift and injection rate.

distributed in the whole engine combustion chamber, could be coupled with quiescent combustion systems. In this sense, a diesel HCN concept could be an alternative solution, as shown in Fig. 1.

Another potential application of a high-pressure HCN could be relative to the Gasoline Direct Injection Compression Ignition (GDICI) engines. Research interest is growing up on this kind of engine due to its capability of producing very low PM and NOx emissions with a fuel efficiency comparable to diesel's one [5].

Literature studies on the GDICI technology indicate that complex injection strategies coupled with an accurate control of the fuel metering are crucial features for the development of this type of engines [6,7].

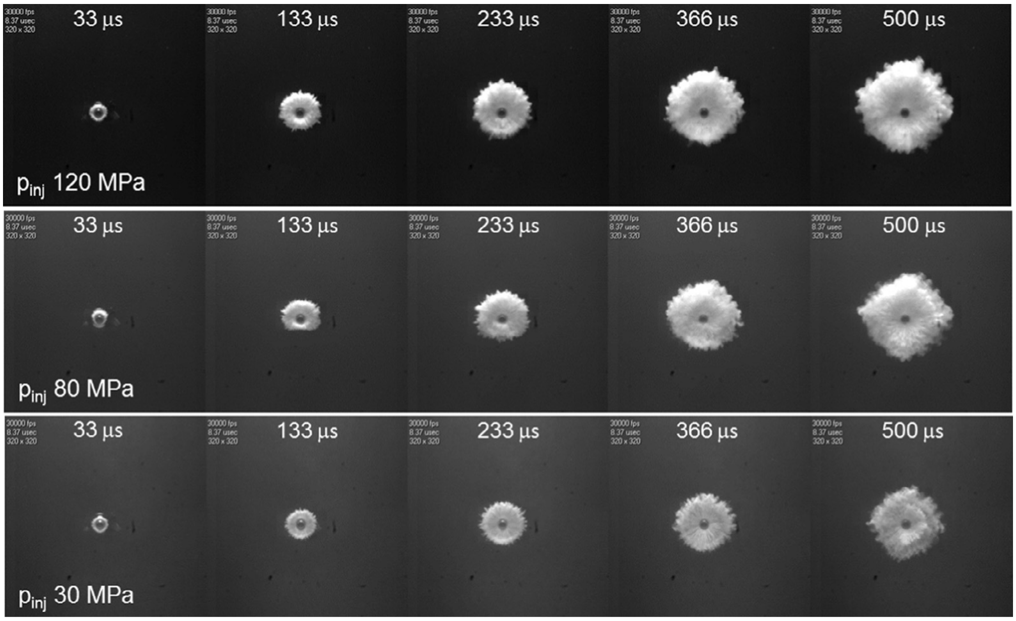

Fig. 4. Liquid spray sequence at different P_{inj} for Q_{inj} 30 mm^3/shot.