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# Effect of open cell metal porous media on evolution of high pressure diesel fuel spray

Iman Sohrabiasl [a,*], Mofid Gorji-Bandpy [a], Alireza Hajialimohammadi [b], Mostafa Agha Mirsalim [c]

[a] Mechanical Engineering Department, Babol University of Technology, Babol, Iran
[b] Mechanical Engineering Department, Semnan University, Semnan, Iran
[c] Mechanical Engineering Department, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

The idea of using porous media in internal combustion engines is proposed recently for charge homogenization. In this paper, the idea of using metallic porous media instead of ceramic type has been introduced and the macroscopic characteristics of high pressure diesel fuel spray has been studied in interaction with this type of porous media. High speed schlieren imaging method is used to capture the spray development process and evaluate time-dependent characteristics of the spray. The Spray characteristics such as tip penetration and spray projected area has been compared with free spray case and spray interaction with metal PM. Several parameters such as PM pore density, thickness of PM, distance between PM and injector tip has been investigated under different injection and chamber pressures. The results show that interaction with PM could reduce the spray tip velocity and increase spray projected area which proportionally increase the fuel-air mixture homogenization inside the chamber. Post processing of the spray images also indicated that the spray pattern (before and after interaction with PM) strongly depends on the PM pore density and injection pressure.



## 1. Introduction

Diesel engines are recently receiving more attention in the passenger car market due to their higher fuel efficiency and torque characteristics compared with gasoline engines. It is well known that diesel engine combustion produces higher particulate emissions due to the formation of heterogeneous mixture inside the cylinder [1,2]. Future diesel engines will have very low or near-zero emissions with the lowest fuel consumption under all engine operating conditions. This could be possible with uniform and homogeneous combustion concept. Homogeneous mixture formation is the most effective factor in developing a homogeneous combustion and significant reduction of emissions of internal combustion engines [3].

Two typical "controllers" are available for determination of air-fuel mixture quality in conventional engines: "air flow" and "fuel supply" conditions. For air flow, three groups of parameters have to be considered: volumetric efficiency, which represents the mass of air supplied to the cylinder, flow structure in the cylinder which represents a macrostructure of the in-cylinder flow field (e.g., swirl, tumble and squish flows), and turbulence level and its scales which represents a microstructure of the in-cylinder flow field [1]. Several concepts such as variable valve timing (VVT), geometry of the port/valve assembly, piston crown shape and valve location in the cylinder head significantly influence on the in-cylinder flow field and mixture formation quality [2–4].

Similar complexity in process optimization is observed in the case of "fuel supply" and spray formation conditions. Current strategies such as high pressure injection and multiple injections are used to improve the injection parameters like instantaneous flow rate, spray macroscopic characteristics. These features determine conditions for air entrainment, fuel vaporization, spatial distribution of fuel in the combustion chamber and mixture formation [5–7]. These technologies and even combinations thereof, cannot solve the problem of engine out emissions under all operating conditions.

For a homogeneous combustion process, control of ignition timing and heat release rate under a wide range of operating conditions (loads and speeds) is critical. This is of special importance in HCCI (Homogeneous Charge Compression Ignition) engines which is interesting research subject for recent works [8,9].

One of the promising technologies for homogenization of the combustion process is using porous-medium (PM) inside the combustion chamber. Using this approach a clean and flameless combustion with homogeneous temperature field will be produced.

* Corresponding author.
*E-mail addresses:* sohrabiasl@gmail.com, sohrabiasl@stu.nit.ac.ir (I. Sohrabiasl).

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**Nomenclature**

| | | | |
|---|---|---|---|
| ECU | electronic control unit | t | time (ms) |
| Pamb | ambient pressure (bar) | Tr | threshold value |
| Pinj | injection pressure (bar) | SOI | start of injection |
| PM | porous media | S | tip penetration (mm) |
| PPI | pore per linear inches (–) | $\alpha$ | spray cone angle (deg) |

This can improve current mixture formation strategies of HCCI engines [10]. The PM engine concept, firstly proposed by Durst and Weclas [11,12]. They modified a single cylinder diesel engine to incorporate a PM in the cylinder head. They mounted a porous silicon carbide (SiC) in the cylinder head between the intake and exhaust valves. The experimental result showed very low CO, NOx, and soot emission levels compared to conventional diesel engines.

The most important requirements of PM structures for homogeneous engine applications are porosity, specific surface area, heat capacity, heat transport properties, transparency for fluid flow and flame propagation, pore size, pore density, pore structure, thermal resistance and mechanical resistance [10].

The idea of PM homogenization, was an interesting research object for recent years. Weclas [13] described the characteristic phases of liquid-jet interaction with the (cold) porous medium as following phases (Fig. 1): Phase A: free space between nozzle outlet and porous medium surface, Phase B: jet reflection from the interface, Phase C: jet propagation throughout (inside) the PM volume, Phase D: fuel spray propagation after PM. The spray propagation in each phase depends on the injection parameters, nozzle geometry, distance from the nozzle outlet as well as on the pore size, PM material, its density and the wall thickness of the pore junctions.

Weclas and Cypris [14] introduced the concept of “distribution nozzle” based on a common-rail diesel nozzle and a distributor element made of a highly ceramic porous ring. They showed that a multi-jet splitting effect is the reason for wide spatial spreading of the impinging diesel spray. They also reported significantly reduction in spray axial penetration and velocity after interacting with PM. They also investigated heat release process in a constant volume combustion chamber and in porous reactors and the results were investigated in a wide range of initial pressures and temperatures under engine-like conditions [15].

Shahangian et al. [16] studied the influence of ceramic porous medium on the air-fuel mixture formation with digital image processing method. Their results showed that multi-jets are produced after interaction with ceramic PM and the fuel reflection from PM surface because of closed pores is significant.

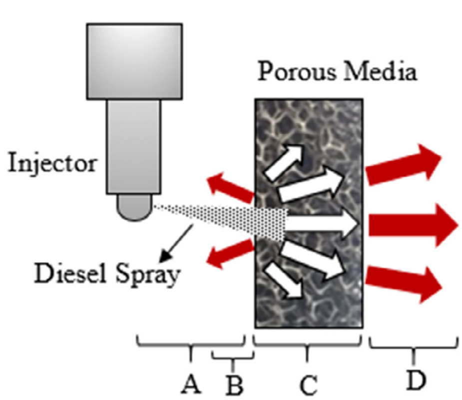


**Fig. 1.** Characteristic phases of diesel spray interaction with a porous structure [13].

In a PM engine, the PM can be placed in each of the following locations: cylinder, cylinder head and piston. Kannan and Tamilporai [17] investigated the Diesel engine emissions with low porosity (18%) ceramic PM that was placed in the piston crown. Their results showed that nitrogen oxide and soot of PM engine are lower than the conventional engine. Kannan and Vijayakumar [18] studied a PM diesel engine performance with a porous medium (porosity 75%) installed in the cylinder head instead of piston crown. The position of PM was between the intake and exhaust valves. They also developed a theoretical model for predicting the performance and emission characteristics of a PM engine. They found that NOx, CO and HC emissions are lower for PM engine compared with conventional engine. Several numerical studies in PM engine has been conducted to investigate the effects of the PM properties on the compression ignition engines [19–22].

Common material that was used in previous research works was ceramic porous media with materials like Al2O3, ZrO2 and especially SiC [14–18]. Because of brittle behavior of ceramic PM, it cannot withstand high injection pressures that make it improper for engine applications. In this study high porosity metallic porous medium (metal foam) has been used. Possibility of inserting metallic PM in cylinder head or piston manufacturing process, higher thermal conductivity and better air-fuel mixing are advantages of metallic PM compared with ceramic type. The number of closed pores in the metal porous structure are also less than ceramic one even in high densities. This feature influences significantly on the fuel distribution and mixture formation in the chamber. The Nickel properties such as melting point, thermal conductivity and Vickers hardness are 1728 K, 90.9 W/(m K) and 638 MPa, respectively. Which indicates that Nickel could well withstand the thermal and mechanical operating conditions of the engine.

In the present work, the diesel spray interaction with metal PM is studied experimentally for different injection and ambient pressure conditions. Spray characteristics such as tip penetration and spray projected area has been compared with free jet case and spray interaction with different PM pore densities has been investigated.

## 2. Experimental setup

### 2.1. Facility and conditions

The experimental setup consists of a stainless steel constant volume chamber (CVC) with optical windows that was designed and built in previous work [23]. The combustion chamber was equipped with high pressure air feeding line, a common rail diesel fuel injection system, schlieren imaging system and a control unit. The experimental set-up is shown in Fig. 2 schematically.

The CVC has a diameter and length of 135 mm. Two sides of this chamber are fitted with quartz windows to provide optical transmission path for parallel light beam. The glasses thickness are selected such that can withstand static pressures up to 100 bar. Initial pressure of chamber was adjusted by a pressure transducers with a range of 0–30 bar. The Nitrogen was supplied from a standard, 20 MPa tank. The internal pressure of the $N_2$ vessel was