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# Numerical analysis of methane direct injection in a single-cylinder 250 cm$^3$ spark ignition engine

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**Abstract**

The paper shows the results of the numerical tasks of a study aimed to evaluate the potential of low-pressure (< 20 bar) direct injection systems for internal combustion engines fed with gaseous fuels. Starting from the geometry of a low-cost commercial injector already available for GDI uses, a 2D axisymmetric CFD analyses is performed to assess the influence of injection pressure and valve and seat-valve profiles on jet characteristics, methane-air mixing, and charge distribution at ignition time. Then 3D simulations for the motorcycle single cylinder test-engine are carried out considering as much as possible combustion chamber details and realistic boundary conditions. Although it is possible identifying which operating and geometrical details of injection system are able to support complete mixture homogeneity, this study shows tremendous difficulties, in case of gaseous fuels, to realise satisfactory stratification charges that would be required to obtain satisfactory performance at partial loads.


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*Keywords:* Direct injection, gas engine, methane, spark ignition, poppet valve, outward opening, CFD.

## Biographical

Dr. Alberto Boretti has been senior researcher and manager in the automotive industry for about 20 year and associate and research professor of engineering mechanical and automotive in the academy for 6 years. He is the author of more than 240 peer review papers, 2 books and 3 book chapters.  He has been working on CFD since 1983 covering many different applications. Dr. Stefania Zanforlin is Assistant Professor in Fluid Machinery at the University of Pisa. She has an MSc degree in Chemical Engineering and a PhD in Energetics. She has 18 years of experience in CFD tools

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applied to internal combustion flows (reciprocating engines) and external flows (wind turbines). She is author of about 40 papers concerning internal combustion engine investigations: Diesel combustion modelling; fluid dynamics of charge stratification in gasoline direct injection engines; direct injection systems for engines fed with hydrogen and natural gas.

## 1. Introduction

In the recent years, even more attention is paid to alternative fuels which can agree to both reducing the fuel consumption and the pollutant emissions.

Large bore spark ignited engines for power generation fed with natural gas, bio-gas or syngas entail high thermal efficiency by adopting lean-burn premixed strategy, turbocharging and Miller cycle [1]; natural gas and bio-gas ignition is usually achieved by mean pilot ignition in a pre-chamber [2], syngas does not need it because of the satisfactory ignition and combustion properties of hydrogen that is one of the syngas components [3].

Among gaseous fuels, Compressed Natural Gas (CNG, which is made by ~ 96% of methane) and bio-methane are considered two of the most interesting in terms of engine vehicular application. They represents an immediate advantage over other hydrocarbon fuels leading to lower $CO_2$ emissions tanks to their lower carbon content. Compared to gasoline, $CH_4$ has wider flammable limits and better anti-knock properties, yet lower flame speed that could be enhanced by adding small amount of hydrogen [4, 5]. Moreover, CNG is affordable and available worldwide.

Usually, CNG engines are developed by integrating CNG injectors in the intake manifold of a baseline gasoline engine, thereby remaining gasoline compliant. However, this does not lead to a bi-fuel engine but instead to a compromised solution for both gasoline and CNG operation.

Direct Injection (DI) provides higher volumetric energy of the mixture and therefore higher engine specific power; moreover the in-cylinder gas injection and post-expansion lead to the mixture temperature decreasing that allows higher boost pressure and higher efficiency. In the last decade sophisticated high-pressure systems have been developed [6] that properly agree to the homogeneous mixture requirements of full load operation. However, high-pressure injection systems are penalised by a low range or by the need of an on-board re-compression system.

DI would give the maximum advantages with respect to Port Fuel Injection (PFI) at partial loads if it could generate proper fuel stratification that, independently of the fuel (liquid or gaseous), increases efficiency, decreases cooling losses, extends lean operation rage and reduces cycle-to-cycle variation [7]. Charge stratification is a challenging task in case of gaseous fuels, indeed extreme difficulties occur when conventional approaches (efficacious enough for gasoline) are adopted: auto-confining injectors, piston bowls or air-wall guided methods. Recent studies focused on medium-high injection pressure demonstrated in some measure acceptable results [8, 9].

The present research is motivated by the actual trend of the increasing use of gaseous fuels, and by the need to study and develop simple, reliable and less expensive injection systems; since medium-low pressures should be preferable also to extend the vehicle range (by means a more complete use of the on-board storage tank) we assumed injection pressures below 20 bar.

Our main objective is to contribute to achieve a deep insight into the physical mechanisms involved in the gaseous injection and in-cylinder mixing processes and to understand how the injection system geometrical details and the operating pressure can determine homogeneous or stratified charge characteristics.

**Nomenclature**

| | | | |
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| $\Phi$ | equivalence ratio = $(air/fuel)_{actual}/(air/fuel)_{stoichiometric}$ | EVC | Exhaust Valve Closing |
| ATDC | After Top Dead Centre | IVC | Intake Valve Closure |
| BDC | Bottom Dead Centre | IVO | Intake Valve Opening |
| BTDC | Before Top Dead Centre | PFI | Port Fuel Injection |
| CA | Crank Angle | RPM | Revolution Per Minute |
| CNG | Compressed Natural Gas | SI | Spark Ignition |
| COV | Coefficient Of Variation | SOI | Start Of Injection |
| DI | Direct Injection | TDC | Top Dead Centre |