PhD proposal title: Experimental and numerical investigations of DI engine fuelled with CNG and hydrogen: application to a Plug-in Hybrid Electric Vehicle (PHEV)

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- **Collaboration:**

This thesis will be carried out with the collaboration of Istituto Motori CNR (Naples-Italy) for the experimental approach. Web: www.im.cnr.it

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Keywords : DI engine, CNG and hydrogen combustion, engine performance, emissions, Plug-in Hybrid Electric Vehicles (PHEV)

Context

Reduction of CO_2 emissions from transportation is mandatory to limit global warming. New Energy Vehicles (NEV) need to be used widely in order to reach this goal. NEV include Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV) and Fuel Cell Electric Vehicles (FCEV). From a Life Cycle Analysis point of view, considering the CO_2 emissions produced by battery manufacturing and during vehicle use, the most promising technology is the PHEV. Even further Life Cycle CO_2 reduction can be achieved by running the internal combustion engine on carbon neutral fuels like bio-CNG or so-called green Hydrogen.

However, the internal combustion engine remains a source of gaseous pollution in urban areas. The combustion process has to be further improved to comply with latest and most stringent exhaust emission standards. One way to achieve this objective is the use of eco-friendly fuels to reduce engine-out emissions, including CO_2, in PHEV system. Gaseous fuels like methane and hydrogen are the most interesting for engine application. The combustion of gaseous fuels is cleaner with respect to liquid fuels : CO, PM (particulate matter) as well as CO_2 emissions are strongly reduced because of the low carbon-to-hydrogen ratio. In combination with Direct Injection, near zero exhaust pollutant emissions can be achieved.

Highlights

- Direct injection of CNG or H_2 in internal combustion engine can be a challenging and innovative technology.

- Experiments can be performed using complementary diagnostics based on indicating and optical measurements in order to obtain a better compromise in terms of engine performance and emissions.
- Numerical simulations can be performed by developing a new approach based on one-dimensional model applied to a few rays to describe the combustion process, similar to 3D approach with less computational time.
- The analysis of results obtained by numerical and experimental approaches can be used to develop more accurate sub-models (for examples: combustion, injection strategies,…).
- The study will allow to define the optimal internal combustion engine settings for PHEV operation in real-world conditions, with respect to exhaust pollutant emissions and life cycle CO2 emissions.

PhD project

The goal of this study is to show that hybrid solution will be able to contribute to reduce environmental impact when PHEV solution is used by running the internal combustion engine on carbon neutral fuels like bio-CNG or so-called green Hydrogen.

The thesis projet includes two complementary parts : numerical modeling approach and experimental approach. These two parts will be completed by a third part dealing with the PHEV analysis.

- ***Modeling phase :***

  The aim of the modeling phase is to develop in-cylinder processes for a complete engine cycle. Instead of using three dimensional models which are time consuming, the idea here is to use a previous approach based on one-dimensional model to describe the combustion [1-2]. The one-dimensional model will be based on a thin flame front, described with the flamelet assumption. It includes a CFM (Coherent Flame Model) similar to the one implemented in commercial 3D codes (KIVA, CONVERGE, …). The turbulence will be taken into account through a (k-ε) model, which includes the effects of swirl and tumble in the combustion chamber. The model will be built as a set of n one-dimensional (n-rays, see figure 1) equations to reproduce the same mathematical structure as the equation of three-dimensional model. This approach allows to represent the effect of nonhomogeneous fuel-air mixture in the chamber by another way than three-dimensional models. In addition, reduced oxidation models have to be included in the global model in order to predict engine out emissions of CO, HC, NOx and PM.

- ***The experimental approach (for more details please see references*** [3] and [4]) ***:***

  The thermo-fluid dynamic phenomena occurring in the engine cylinder can be optimized using advanced non-conventional diagnostics based on the use of transparent engines and high spatial and temporal resolution optical diagnostics. This characterization of the process fueled with CNG or H_2 can be carried out in small optical cylinder or in research multicylinder engines (Figure 2 shows single cylinder optical engine). The injection and combustion phases will be analyzed through the optical window on the piston head, as shown in Fig. 2.

- The gaseous fuel sprays can be evaluated through 2D Mie scattering.
- The combustion process development can be investigated by high-speed imaging of flame chemiluminescence over a series of consecutive engine cycles.

The images acquired and post-processed can be used in order to calculate in-cylinder rates of flame growth. This approach allows the acquisition of important information about the flame propagation and the abnormal combustion events. All the optical data can be correlated to the in-cylinder pressure-based indicated measurements and to the gaseous emissions and engine performances.

Steady-state measurements of CO, CO_2, TUHC (Total Unburned HydroCarbon) and NOx will be performed in the undiluted exhaust. Gaseous emissions will be measured by AVL DIGAS 4000 and Horiba MEXA7200 and CH_4 emissions by means of an AVL AMAi60HC SA flame ionization detector (FID). Particle size will be quantified by DMS500.

The data coming from this phase will be used as a part of the modeling approach in order to validate in-cylinder pressure traces and engine out emissions. These data will be used also to improve the sub-models retained in this study.

- **PHEV analysis :**

This part of this study will be targeted to define the optimal internal combustion engine settings for PHEV operation in real-world conditions, with respect to exhaust pollutant emissions and life cycle CO2 emissions. This step will be performed by the developed global model.

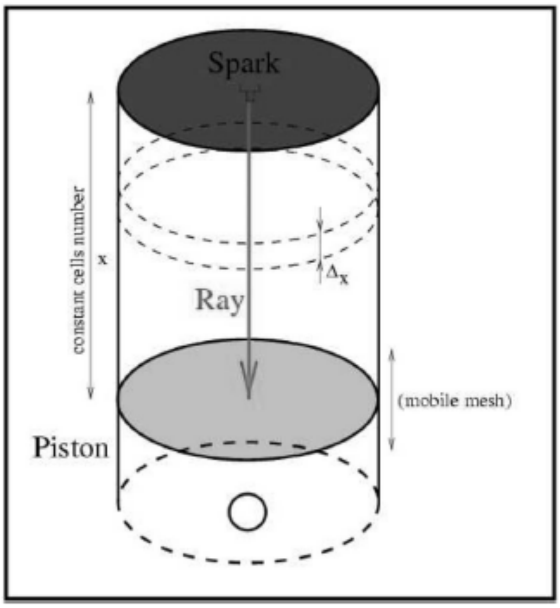

Figure 1. Model's geometry

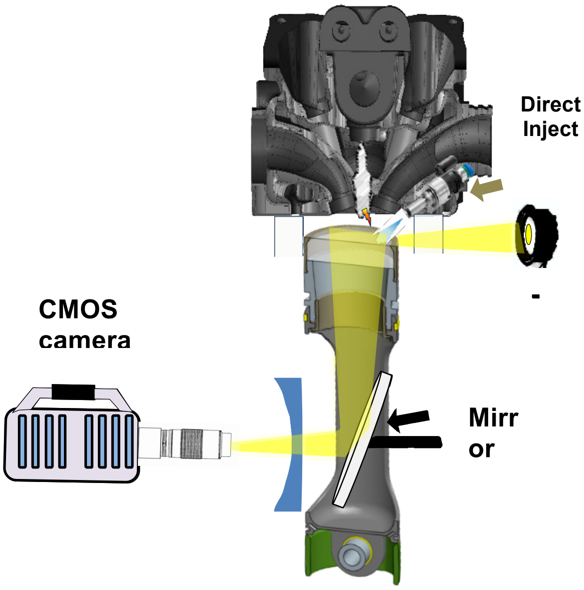

Figure 2. Layout of optical engine and optical apparatus

References

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[3] S. Di Lorio, P. Sementa, B.M. Vaglieco. Analysis of combustion of methane and hydrogen-methane blends in small DI SI (direct injection Spark ignition) engine using advanced diagnostics. Energy 108 (2016) ; 99-107.

[4] E. Distaso, R. Amirante, E. Cassone, P. De Palma, P. Sementa, P. Tamburrano, B. M. Vaglieco. Analysos of the combustion process in a lean-burning turbulent jet ignition engine fueled with methane. Energy Conversion and Managmente 223 (2020) article 113257.

Skills required in:

- Combustion.
- Principles of internal combustion engine
- Numerical simulations.
- Chemical kinetics