

## **Thesis's summary (Abstract)**

*As we receive about 100 subjects every year, please limit the summary to one page*

This position would concern theoretical/numerical modelling of combustion. The aim of the modelling work is to establish physical-sound mathematical models which are capable to shed some light on present issues for reliable design of combustion[1]. In particular, Homogeneous-charge compression-ignition (HCCI) engines offer the potential for diesel-like efficiency with low NO<sub>x</sub> and particulate emissions. There has been ongoing interest in HCCI engines for at least 20 years, and HCCI has been the subject of intense research since the late 1990s. An unresolved fundamental issue is the relative importance of hydrodynamics (turbulence) compared to chemical kinetics on the combustion process. Chemical kinetics clearly dominates under truly homogeneous conditions. But turbulence is expected to play an increasingly important role as conditions depart from this ideal. Both experimental and computational studies have shown that turbulence can influence ignition timing and emissions for practical HCCI engines[2].

The aim of the thesis will be to elucidate further the role of turbulence/chemistry interactions (TCI) on HCCI autoignition and emissions.

In summary, the mathematical and physical structure of the advection-reaction-diffusion equation that is typical for combustion phenomena will be studied.

Though in principle velocity-field and concentration equations are coupled, we will first simplify the problem considering the assumption of no back-reaction of the reactants concentration on the velocity field. In this configuration a deep analysis of the ignition-type nonlinearity on the asymptotic behaviour of the reaction will be carried out. The importance of turbulence and compressibility will be studied with respect to changes in the velocity field. Analytical, numerical and experimental velocity fields will be used.

In a second time, the complete compressible Navier-Stokes equation and the modelled reaction-diffusion equation previously analysed will be coupled. That should help us to give some theoretical explanation to the experimental observations of the gradual transition between conventional spark-ignited (SI) propagating flame combustion and homogeneous charge compression ignition (HCCI) in fuelled gasoline engine. Our objective is to better understand the transition process in terms of characteristic changes to the combustion stability and to indicate the precise role played by turbulence.

The work will use various experiments as basis for verifying the modelling. The experiments will be mainly from experimental research carried out at the division by the means of the rapid-compression machine available in Saint-Cyr[3].

## **Extended Summary of the subject**

### ***Context of the study***

The internal combustion engine is one of the key drivers in modern industrial society. Without the transportation performed by the millions of vehicles, we would not have reached the living standard of today. There are two types of internal combustion engines: spark ignition (SI) and compression ignition (CI). The major disadvantage of SI engines is its low efficiency at partial loads. The compression ratio in SI engines is limited by knock and can normally be limited in the range from 8 to 12 contributing to the low efficiency. Conventional diesel combustion, as a typical representation of CI combustion, operates at higher compression ratios (12–24) than SI engines. In this type of engine, the air–fuel mixture auto-ignites as a consequence of piston compression instead of ignition by a spark plug. The

processes which occur between the two moments when the liquid fuel leaves the injector nozzles and when the fuel starts to burn, are complex and include droplet formation, collisions, breakup, evaporation and vapour diffusion. The rate of combustion is effectively limited by these processes. An ideal combination would be to find an engine type with high efficiency of diesel engines and very low emissions of gasoline engines with catalytic converters. One such candidate is the process known as homogeneous charge compression ignition, HCCI. HCCI is characterised by the fact that the fuel and air are mixed before combustion starts and the mixture auto-ignites as a result of the temperature increase in the compression stroke. Thus HCCI is similar to SI in the sense that both engines use premixed charge and similar to CI as both rely on auto-ignition to initiate combustion. For that reason, homogeneous charge compression ignition (HCCI) in internal combustion engines is of considerable interest because it can significantly reduce flame temperature and nitrogen oxide formation. In this mode of pre-mixed combustion, ignition is initiated by compression instead of a spark and the reactions occur very rapidly and uniformly throughout the combustion chamber. With HCCI there is little or no flame propagation as in conventional spark-ignited combustion. In order to initiate HCCI at the correct point in the compression stroke, it is typically necessary to preheat the fuel-air mixture to within a relatively narrow temperature window prior to compression. Furthermore, other studies have shown that the stability of HCCI operation is influenced not only by the temperature but also the composition of the initial charge [4,5]. In practical engines the appropriate level of preheating and mixture composition is very difficult to achieve over the entire range of speed and load, and thus there are many operating points under which the HCCI mode is unstable. In practice it is frequently necessary to switch between HCCI and spark-ignited (SI) propagating flame (PF) combustion as engine conditions change.

### ***Main objectives***

Several recent publications and presentations [6–9] have addressed HCCI control but with few exceptions (e.g., [7]) there has been limited exploration of the fundamental nature of the PF–HCCI transition process. mode is unstable. In practice it is frequently necessary to switch between HCCI and spark-ignited (SI) propagating flame (PF) combustion as engine conditions change. This rationale can be indeed extended to turbulent combustion in general. While, numerical simulations and analysis of complex configurations of turbulent combustion are often possible nowadays[10], a fundamental understanding from a physical and mathematical point of view of the process underlying those phenomena is far from being satisfying.

The aim of this study should be to describe the relation between the reaction-diffusion equation and the whole process dynamics and to explain the bifurcation which characterises the transition between PF and HCCI combustion.

### ***Expected Results***

More in detail, we would like to explain better the role of turbulence and molecular diffusion on the development of the instability which guides the ignition process.

We shall study the advection-reaction-diffusion equation confined in a closed domain and stirred by different velocities. We shall discuss the mixing and reaction efficiency in systems advected by a given velocity field,  $u$ , in closed domains. For mixing efficiency we intend the capacity of a flow to spread particulate inert material starting from a small region over the whole system domain[11]. The velocity field will be chosen to be analytical (chaotic and non chaotic), numerical and possibly also taken from experiments[3]. Concerning numerical simulations, a full calculation of the complete set of compressible Navier-Stokes equations

will be carried out. Notably, we should use the house-developed code ntmix for DNS and possibly the AVBP for LES. It is worth saying that both codes have been developed and are maintained by CERFACS and thus little numerical work will be required. This should enable us to study in detail the quenching phenomenon of ignition-type reaction dynamics in a compressible flows and to develop a simplified model based on a physically controllable localisation approximation for the concentration field. The dependence of the critical initial condition width  $l_c$  on the relevant parameters will be also established by means of numerical experiments and dimensional reasoning.

Final simulations and analysis should then, first, make clear the fundamental role played by initial turbulence energy level in the balance between SI and HCCI regimes. Second, they should elucidate the influence of the turbulence length scales spectrum on the ignition process. Namely, turbulence locally impacts the ignition process by straining nascent flames and by mixing partially-reacted fluid.

### ***Collaborations***

The collaboration with the department of physics of the University of Rome (namely with Prof. A. Vulpiani) is envisaged for the theoretical part of the work.

The collaboration with Poinso's equipe in numerical combustion is also considered for helping in simulation means and their use. Other collaboration might be considered.

### ***References***

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