Abstract

Fuel direct injection represents one of the key turning points in the development of the Diesel engines. The appeal of this solution has been growing thanks to the parallel advancement in the technology of the injection hardware and in the knowledge of the physics involved in the spray formation and combustion.

In the present thesis, the effect of partial needle lift and injection rate shaping has been investigated experimentally using a multi-orifice Diesel injector.

Injection rate shaping is one of the most attractive alternatives to multiple injection strategies but its implementation has been for long time impeded by technological limitations. A novel direct-acting injector prototype made it possible to carry out the present research: this injector features a mechanical coupling between the nozzle needle and the piezo-stack actuator, allowing a fully flexible control on the nozzle needle movement and enabling partial needle lift as well as the implementation of alternative injection rate shapes typologies. Different optical diagnostics were applied to study the spray development and combustion in a novel continuous flow test chamber that allows an accurate control on a wide range of thermodynamic conditions (up to 1000 K and 15 MPa). In addition, hydraulic characterization tests were carried out to analyze the fuel flow through the injector nozzle.

Partial needle lift has been found to affect the injection event, reducing the mass flow rate (as expected) but also causing a reduction in the effective orifice area and an increase on the spreading angle. Moreover, at this condition, higher hole-to-hole dispersion and flow instabilities were detected. Needle vibrations caused by the needle interactions with fuel flow and by the onset of cavitation in the needle seat are likely the causes of this behavior.

Injection rate shaping has a substantial impact on the premixed phase of the combustion and on the location where the ignition takes place. Furthermore, the results proved that the modifications in the internal flow caused by the partial needle lift are reflected on the ignition timing. On the other hand, the analysis of the experimental data through a *1D* spray model revealed that an increasing mass flow rate (e.g. *ramp* or *boot* injection rate profiles) causes an increase in the fuel-air equivalence ratio at the lift-off length and a consequent higher soot formation during the diffusive phase of the combustion. Finally, the wide range of boundary conditions tested in all the experiments served to draw general conclusions about the physics involved in the injection/combustion event and, in some cases, to obtain statistical correlations.