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IN-ENGINE COMBUSTION: THERMO-FLUID DYNAMICS, INJECTION, CONTROL ASPECTS

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Abstract. *Scientific community and stakeholders expect that the Internal Combustion (IC) Engine will remain the primary powertrain in 2020 perspective. The development of IC engines involves both the direct control of the in-engine thermo-fluid dynamic processes for reducing the pollutant formation, and the aftertreatment of the exhaust gases so as to abate the residual pollutants produced by the combustion process. In addition, the needs for further consumption reduction (CO_2), as well as the quality, availability and distribution problems posed by alternative fuels will call for the realization of efficient and clean diesel engines and will increase the role played by the use of biofuels, compressed natural gas (CNG), H_2 and liquefied petroleum gas (LPG).*

The lecture will discuss the main diagnostic and predictive approaches that can be applied to investigate combustion and to develop new engine control strategies. Two diagnostic approaches are presented, which are both based on the analysis of measured in-cylinder pressure traces. In spark ignition (SI) engines, a quasi-dimensional multizone combustion model can account for the non-uniform spatial distribution of in-cylinder burned gas thermodynamic and chemical properties. The described approach is capable of calculating heat release rate, temperature evolution and NO_x formation in the combustion chamber, and can be coupled with a CAD procedure for the computation of burned-gas mean expansion and burning speeds. In diesel engines, a premixed-diffusive multizone model is developed according to a combustion concept close to the two-stage quasi-steady process proposed by J.Dec and by Sandia Lab. researchers.

With reference to SI engine predictive models, the entrainment of fresh mixture through the flame front can be described according to non-fractal or fractal approaches. The fractal approach can take account of the effects of both radical species and heat transfer across the flame front by fine-scale turbulence eddies, in addition to the increase of the actual flame front area caused by the wrinkling effect of turbulence, which is the only effect considered in the conventional approach.

Multidimensional fluid dynamic computational codes with reliable turbulence models are useful design and investigation tools for IC engines, in-cylinder flow phenomena being critical to the combustion process and related emission sources. Although a variety of turbulence models has been proposed, the assessment of even the most widely used k-ε model is still lacking, especially for bowl-in-piston engines. A survey of k-ε turbulence model variants and their numerical implementation for in-cylinder flow analysis is provided.

The lecture will also review the potential of CNG engines to reduce exhaust emissions and to improve fuel conversion efficiency, as well as the new combustion concepts for post-EU5 diesel engines.

With reference to CNG SI engines, current research is focused on naturally aspirated bi-fuel engines and small turbocharged CNG engines. On the one hand, most current CNG vehicles continue to retain a bi-fuel capability due to the scarcity of public CNG fueling stations and as a means of overcoming range limitations for those applications where in-vehicle limited storage capacity can represent a problem. On the other hand, considering the incremental load imposed by on-vehicle high-pressure storage tanks, turbocharging of CNG engine emerges as the unique technique able to guarantee performance levels comparable to those of modern gasoline and diesel engines. The results of systematic experimental investigations are presented, so as to compare full-load performance, fuel consumption and exhaust emissions of different CNG engine types.

In diesel engines, HCCI combustion concept can be applied to a variety of fuels. Combustion phasing and operation range can be controlled through the fuel characteristics. It has been recognized that advanced control strategies of fuel/air mixture are key aspects for the HCCI combustion control. Both stratification strategies and low temperature combustion, with recirculating exhaust gas dilution, have the potential of extending the HCCI operation range to high loads.

Finally, with reference to diesel engines working by advanced conventional combustion concepts, the potential of piezo- versus solenoid-driven injector technologies is discussed by correlating hydraulic and multicylinder engine testing.