Recent understanding for controlling emissions from LD compression ignition engines

Kumara Gurubaran Ramaswamy, Dimitrios P. Touloupis, Christos Keramiotis, Nikolaos Soulopoulos, Christopher Hong, and George Vourliotakis

Department of Mechanical Engineering, Imperial College London

The advantage of Diesel engines, namely their efficiency, is well known: for long-distance haulage, the ubiquity of the heavy–duty diesel is unassailable. The market penetration of the light duty (LD) diesel engine, in contrast, is threatened: hybridisation of the spark ignition engine results in efficiency which can be comparable. Despite the substantial reduction in emissions from LD diesel engines due to the introduction of legislation from the 1990s, it is argued that the LD diesel inevitably exposes urban populations to emissions of NOx and of particulates, the levels of which may well result in risks to health and even in premature death (in 2011, the Environmental Audit Committee of the United Kingdom's House of Commons said: "The costs to society from poor air quality are on a par with those from smoking and obesity"). In addition, the current driving cycles which are used to measure emissions, on which the legislative limits are based, are held by some to be misleading of 'real-world' driving emissions. As a consequence, several cities in Europe have introduced 'low emission zones' and London will include passenger cars in the "ultra-low emission zone" which is to be introduced in 2020.

In addition to the existing strategies of downsizing, downspeeding and hybridisation, there are at least three methods to reduce "engine – out" emissions, as opposed to "tailpipe out" emissions which relate to catalysts, particulate filters and associated improvements with these technologies. These are, in increasing order of technological complexity, to: (1) Improve injection strategies, particularly as the capabilities of common rail fuel injection equipment improve; (2) Implement so-called "ultra-boost" strategies, including low-pressure exhaust gas recirculation, which may result in an improved "NOx-soot" trade off; (3) Modify the fuel characteristics, to promote "premixed enough" combustion. This presentation will briefly present results for these three approaches.

1. Improved Injection Strategies. The present work aims to visualise combustion in an extensively characterized single cylinder Ricardo Hydra engine at Imperial College London. The work investigates the effect of low levels CO_2 addition on the combustion characteristics inside a single cylinder optical engine operated under low load conditions. The effects of dilution levels (up to 7.5% mass flow rate CO_2 addition), the number of pilot injections (single or double pilot injections) and injection pressure (25 or 40 MPa), are evaluated towards the direction of achieving a partially premixed combustion (PPC) operation mode.

The engine was operated under low IMEP levels of the order of 1.6 bar at 1200 rpm and with a CO_2 diluent enhanced atmosphere resembling an environment of simulated low exhaust gas recirculation (EGR) rates. Flame propagation is captured by means of high speed imaging and OH, CH and C_2 line-of-sight chemiluminescence respectively. Each of the above species is a proxy of a fundamental combustion property; OH* is related to the oxidation zone, CH* to the

heat release zone and the flame front, while C_2* is indicative of fuel-rich areas. The combined analyses of the obtained results were made under the perspective of identifying the induced alterations in flame structures and, possibly, combustion modes, and their manifestation in the global in-cylinder conditions. The increase of CO_2 addition results in lower peak pressures and in an overall delay of the combustion process, while also influences the spatial characteristics of reaction and oxidation zones, as well as differentiates the extent of fuel-rich pockets.

Multiple injections advance the main combustion event and an increase in injection pressure enhances fuel evaporation and mixing while spatially confining the observed flame structures. Overall, operation under relatively slightly diluted conditions with more pilot injection events at higher rail pressure appear to enhance mixing, proving thus an indication of lower emission levels.

2. "Ultra-boost" strategies, including low-pressure exhaust gas recirculation. The reduction of emissions with exhaust gas recirculation (EGR) drawn from upstream of the turbine in a boosted LD engine (so-called high pressure EGR) has been well known for several decades but, particularly in the context of emissions in 'real world operation', there are limits when there is insufficient pressure difference to drive the EGR. The limitation can be overcome by drawing the EGR from downstream of the turbine, so-called low pressure EGR and this can be combined with ultra-boost strategies which result in manifold pressures which greatly exceed current single-stage turbo-chargers. A parametric study performed on a EURO-V diesel engine at Imperial College London has revealed the potential of breaking the established NOx/soot trade-off by introducing higher proportions of EGR at higher boost pressures (up to 4 bar abs). An external unit was utilised to deliver variable boost pressure, in order to maintain all parameters constant apart from boost pressure. Improvements in specific fuel consumption and emissions with moderate levels of boosting at low loads were also obtained. Moreover, the results on low duty metal engine suggest that, at low load and low speed, the effect of EGR on (particularly NOx) emissions is important.

3. **Modify the fuel characteristics, to promote "premixed enough" combustion.** Previous work has demonstrated that single-cylinder CI engines, with relatively modest changes to operating conditions over a wide operating range, can be run with both very low NOx and low smoke as well as at high efficiency on fuels with high resistance to autoignition such as gasoline. The purpose of this work was to run a multi-cylinder engine without any major changes to the engine system on a gasoline fuel at constant fuel demand to get better understanding of the possible practical advantages and challenges. A 2.7 dm^3 Euro IV V6 diesel engine was run on a European standard diesel fuel of 54 CN (Cetane Number) according to the engine map at 1000 rpm and 1500 rpm at different loads. At the same speeds and loads, it was also run on a 84 RON gasoline but with different injection strategies and operating parameters, such as EGR levels. With gasoline, NOx levels comparable to the diesel map point could be obtained but at lower EGR rates, at lower injection pressures and lower brake specific fuel consumption and with extremely low smoke; however the CO and HC emissions were higher. The engine could not be run at high speeds or at loads greater than 12 bar IMEP on gasoline because, without introducing modifications, the fuel overheated and gave rise to vapour-lock problems. Also at high loads, in order to limit NOx emissions, high EGR rates were required but the CO levels were excessive, because the particular turbocharger could not deliver adequate intake pressure at such conditions and hence the intake oxygen levels were too low.

Thus further modifications to the fuel system and an alternative turbocharger would be needed to extend the operating range on gasoline. There appears to be potential for simplifying future CI engines e.g. by using lower injection pressures and replacing lean NOx after-treatment by CO and HC control by using gasoline-like fuels.