Key findings

The significant breakthrough in making 2,5-Dimethylfuran (DMF) reported by Nature and Science respectively in 2007 has made it being considered a new biofuel candidate but previously there was no knowledge about its combustion and emissions in power systems. This world-first research of DMF at University of Birmingham following up the discovery has included a systematic experimental and modelling investigation of DMF as bio-fuel in the direct injection spark-ignition engine.

These investigations have covered the spray, combustion, emissions, simulation, optical diagnostics and hydrocarbon gas speciation. The results have demonstrated the advantages of DMF's higher energy density compared with ethanol, good anti-knock property, lower particulate matter emissions and potentially better cold-start performance. The investigation has quantified its laminar flame speed under various conditions, unregulated emissions and toxicity concerning its impact on the environment. Spray and combustion models for DMF application in SI engines have been developed and validated by quantified experimental results.

The investigators have collaborated with various industrial partners including Jaguar Cars Ltd, Innospec and Green Fuels. Academic collaboration has also been made with Xi'an Jiaotong University and Tsinghua University, both in China. The research of DMF at the University of Birmingham has also involved the School of Chemical Engineering and the School of Bio-science where the production of DMF using super critical water technology and the toxicity of DMF were investigated respectively. The main results of the research have so far been published in 16 refereed the most prestigious international journals, as briefly summarised below.

Spray

The spray characteristics of pure DMF, gasoline, ethanol and DMF-gasoline blends have been studied by the schlieren graph and PDPA techniques in terms of spray penetration, droplet velocities and size distributions in order to investigate the spray behaviour of the new potential fuel, DMF. The spray characteristics of DMF are particularly favourable. The spray pattern when using DMF is very similar to that with gasoline. The DMF spray also has a negligibly larger droplet size than the gasoline spray (Tian, 2010b). Nest DMF and its blend with gasoline have a slightly lower mean velocity than gasoline. For most of the cases, the difference is less than 10m/s. The injection pressure plays an important role in the droplet size. For DMF, gasoline and ethanol, the SMDs decrease to 8.8, 8.3 and 7μm respectively when the injection pressure increases from 50 to 150bar. Increasing the injection pressure benefits the DMF spray more so than ethanol's. It is concluded that spray characteristics of DMF is more close to that of gasoline than that of ethanol.

Optical study of flame

The flame propagation characteristics of 2,5-dimethylfuran (DMF) were performed using the Schlieren optical method (Tian, 2010a). DMF's laminar flame characteristics from a quiescent homogenous mixture in a constant volume vessel using the schlieren method. Of concern is the outwardly propagating spherical laminar flame speed, the Markstein length and the laminar burning velocity of DMF for a range of equivalence ratios (≤1.6) and initial temperatures (50-100ºC). DMF's performance was benchmarked against gasoline and then compared to the current biofuel leader, ethanol. It is found that in terms of flame speed, DMF is similar to gasoline but slower than ethanol. Meanwhile, DMF shows the slowest laminar burning velocity (up to 10% slower than gasoline and 20-40% slower than ethanol at stoichiometry). These behaviors are subject to the effect of equivalence ratio and initial temperature. Flame propagation of DMF in the direct injection SI engine is stuied in the optical engine. It is shown that DMF-gasoline dual-injection combustion has higher flame propagation speed and shorter combustion duration than baseline 100% gasoline PFI. The flame luminance of DMF-gasoline is much higher than ethanol-gasoline and pure gasoline. The engine load conditions have less influence on DMF-gasoline dual-injection flame propagation speed. The results of the flame propagation process and flame speed prove that DMF's existence in the fuel blends will bring the combustion closer to that with pure DMF, even when using low percentages.

Combustion

Detailed combustion analysis has been conducted using DMF. The world's first publication on DMF combustion in engines was made in Energy and Fuels, Impact Factor 2.72 (Zhong, 2010). This used fixed spark timings to investigate the knock suppression ability of DMF compared to gasoline and ethanol. The effect of DMF on combustion using optimised spark timings and loads was then published in FUEL, Impact Factor 3.79 (Daniel, 2011). This was the world's second publication on DMF as engine fuel. Since these two publications, several more journal papers and SAE papers have followed and These included the publication on the effect of various engine parameters, such as engine load, optimum spark timing, injection timing and valve timing when using DMF (Daniel, 2012b) and the effect of split-injection at full load (Daniel, 2012c). The engine performance and emissions are less sensitive to changes in key control parameters than when using DMF compared to gasoline. This was also shown using spark sensitivities (Daniel, 2012a). This allows a wider window for improving performance and/or reducing emissions. Novel fuel preparation techniques have been investigated by comparing traditional externally supplied gasoline-biofuel blends to internally mixed, dual-injection blends. The results using low blends o DMF with gasoline (25% of DMF by volume, or D25) are more efficiently utilised than in external blends (Daniel, 2012d).

Regulated and unregulated emissions

CO_2 emissions using dual-injection were shown to be similar to homogenous DI when using gasoline (Daniel, 2012e). However, the NO_x emissions are much higher with DMF due to higher combustion pressure and temperatures. Furthermore, the particulate matter (PM) emissions can be reduced with dual-injection because gasoline is supplied through PFI. In terms of unregulated emissions, the emissions of the major carbonyls are lower when using DMF compared to gasoline and even less so than ethanol, which heavily emits acetaldehyde and formaldehyde. The formation of benzene and toluene during DMF combustion results in similar benzaldehyde emissions to gasoline. The HC emissions of DMF are dominated by unburned fuel.

Impact to engine hardware and environment

The lubricity of DMF was jointly studied at the Hefei University of Technology in China which revealed a more favourable lubricity of DMF than gasoline (Hu 2012). The toxcity of 2,5-Dimethylfuran (DMF) was investigated by a team in the School of Biosciencs. Compared to the sub-toxic atmospheric concentration of gasoline of around 0.6 mM, DMF is shown to be sub-toxic at intracellular concentrations up to 5 mM in human liver cells. This appears promising because intracellular concentrations will be much lower than those observed in the atmosphere due to the distribution of the compound (Whyley, 2011).