Auto-ignition characterisation of synthetic fuels via Rapid Compression Machine

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Abstract
Availability and sustainability of fuels for road and air transport is essential for economic development and growth of any nation. New alternative fuels provide an opportunity to limit the use of ever declining conventional petroleum oil reserves as well as offsetting CO2 generation from their use. Liquid fuels have the highest energy density for transportation applications and synthetic liquid fuels, which can be produced from renewable non-food bio feedstock offer an exciting opportunity for partial or even total substitution of remaining fossil fuel supplies. It is therefore of great interest to study the fundamental combustion characteristics of these fuels if they are to be used commercially. This work is aiming at characterising the auto-ignition properties of individual fuel components representative of the chemical families present in the synthetic fuels which in this case are toluene, iso-octane, n-heptane, and bio-alcohols; ethanol and n-butanol. The auto-ignition characterisation was made by measurements of ignition delay times, τ. The time τ for these fuels and their blends were measured after rapidly compressed to an elevated pressure and temperature using a Rapid Compression Machine (RCM). RCM provides good platform to study the fuel auto-ignition process without complicated physical effects in engines which are continually changing. However, they are not without problems, practical applications are usually not within the ideal conditions. Different machines have different extent of deviation from ideal conditions, making comparison of results between rigs difficult. In the present study, a dedicated work was conducted to study the difference between the measurements originated from these rigs and were characterised against their deviations from ideal conditions. These cover chemical reaction during the finite compression time, the effects of heat loss during the ignition delay period, the effects of piston displacement (piston bounce), and non-homogeneous auto-ignition. An interesting aspect of the study is that a plot of the measured different delay times at a given temperature, on the separate machines, against the corresponding degrees of reaction during compression, when extrapolated to zero reaction, yield a more accurate delay time for that condition. As the temperature is increased, so also are the oscillatory pressure amplitudes generated at the auto-igniting hot spots. This is in line with other studies of hot spot auto-ignition. Measurements of ignition delay times of different chemical groups separately and when blended with each other were made. They provided an understanding of how their interaction influences the overall ignition delay times. When blended the change of their τ values do not vary linearly especially when the blended components have large difference in reactivities. Toluene for example, which is commonly known for its long ignition delay times, was made extremely reactive when blended with n-butanol. Comparison of addition of bio-alcohols (ethanol and n-butanol) on gasoline surrogate fuel (TRF) showed that at lower temperatures, they both increased the ignition delay times of TRF, while at high temperatures they reduced TRF delay times to almost the same value. n-butanol started to reduce TRF delay times at lower temperatures compared to ethanol. Development of auto-ignition blending laws offers an opportunity to enable quick methods for choosing an appropriate blend for a particular application. In this work, a Linear by Mole (LbM) auto-ignition blending law was proposed, it uses the measured ignition delay times of individual components in the blend and varies them linearly with the fractional concentration of each component. This was found to be satisfactory only for blends of chemical families without NTC behaviour such as CH4/H2, for fuels with NTC behaviour an empirical based law was generated for the conditions studied. Overall, this study has broadened our understanding in auto-ignition behaviour of selected individual fuel components and their blends at varying conditions of pressure, temperature and concentration. It has also enabled substantial development of Leeds RCM to achieve fast compression with good piston damping.