Fuel 209 (2017) 172–183

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Significance of RON and MON to a modern DISI engine

Chongming Wang[a,b], Arjun Prakash[c], Allen Aradi[b], Roger Cracknell[d], Hongming Xu[a,e,*]

[a] University of Birmingham, UK
[b] Shell Global Solutions (Deutschland), Germany
[c] Shell Global Solutions (US), USA
[d] Shell Global Solutions (UK), UK
[e] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing, China

ARTICLE INFO

Keywords:
RON
MON
DISI
Combustion
Indicated thermal efficiency

ABSTRACT

The anti-knock quality of gasoline fuels is a significant contributing factor to the indicated thermal efficiency (ITE) of spark ignition (SI) engines. Historically, the anti-knock quality of gasoline is characterised by two parameters, research octane number (RON) and motor octane number (MON), which are measured in co-operative fuel research engines (CFR) using iso-octane and n-heptane as the primary reference fuels (PRFs). However, due to significant hardware, operating condition and fuelling differences between the CFR and the modern SI engines, the relevance of RON and MON to modern SI engines needs to be re-assessed. In this study, six fuels were designed with independent control over RON and MON. The other key fuel properties, such as the heat of vaporisation, the oxygen content, the lower heating value and the stoichiometric air-fuel ratio (AFR) were kept similar for all the fuels. Among the six fuels, two fuels represent regular- and premium-grade gasoline fuels with respect to octane quality in the North American market. The objective of this study was to assess the significance of RON and MON to the combustion characteristics of a modern SI engine. A single cylinder 4-stroke direct injection spark ignition (DISI) research engine was used as the experimental tool. The engine tests were conducted at the engine speed of 1800 rpm and the engine load ranging from 4 to 20 bar IMEP. Three market representative engine compression ratios (9.5:1, 10.5:1 and 11.5:1) were selected. In addition, the engine K value was calculated at knock-limited engine conditions. The results showed that, under knock-free engine operating conditions and at a fixed engine compression ratio, variation of fuel RON and MON had almost no differential impact on ITE. Under knock-limited operating conditions, increasing MON did not increase ITE, and in contrast, even led to decreased ITE especially when RON was as low as 93 and the compression ratio was high. Under knock-limited operating conditions, when the RON of the fuel was as high as 98, changing the MON up or down only showed combustion phasing benefits/disbenefits without obvious ITE benefit. This is because the octane rating of the fuel was high and in order to differentiate their anti-knock quality, a higher compression ratio than 11.5:1 was needed. The calculated engine K value shows that RON was a more significant influential factor than MON in determining the engine thermal efficiency. RON was found to have a higher impact on ITE at the higher MON of 88 vs. the lower MON of 83.

1. Introduction

The transportation sector is facing pressures of increased light duty mobility demand and more stringent regulations on fuel economy and greenhouse gas emissions [1]. Even though hybrid and electric vehicles are gaining significant support and popularity, conventional vehicles powered by internal combustion engines will still be the main tool for light-duty transportation in the foreseeable future [2]. Therefore, improving the efficiency of internal combustion engines via better engine design is highly relevant [3–6]. Apart from improving the engine

---

Abbreviations: AFR, Air Fuel Ratio; ATDC, After Top Dead Centre; BTDC, Before Top Dead Centre; CA, Crank Angle; CAD, Crank Angle Degree; CFR, Cooperative Fuel Research; CR, Compression Ratio; COV, Coefficient of Variation; DI, Direct Injection; DISI, Direct Injection Spark Ignition; EGR, Exhaust Gas Recirculation; HOV, Heat of Vaporisation; KLSA, Knock Limited Spark Advance; LHV, Lower Heating Value; IMEP, Indicated Mean Effective Pressure; ISFC, Indicated Specific Fuel Consumption; ITE, Indicated Thermal Efficiency; MFB, Mass Fraction Burn; MFB05, Crank angle where 5% of fuel is burned; MFB50, Crank angle where 50% of fuel is burned; MFB90, Crank angle where 50% of fuel is burned; MON, Motor Octane Number; NEDC, New European Driving Cycle; ON, Octane Number; OI, Octane Index; PFI, Port Fuel Injection; Pmax, Peak in-cylinder pressure; PRFs, Primary Reference Fuels; rpm, Revolutions per Minute; RON, Research Octane Number; SI, Spark Ignition; TDC, Top Dead Centre; vol%, Volumetric Percentage; VVT, Variable Valve Timing; η, Indicated Thermal Efficiency

[*] Corresponding author at: University of Birmingham, UK.
E-mail address: h.m.xu@bham.ac.uk (H. Xu).

http://dx.doi.org/10.1016/j.fuel.2017.07.071
Received 23 November 2016; Received in revised form 13 July 2017; Accepted 18 July 2017
0016-2361/ © 2017 Elsevier Ltd. All rights reserved.

hardware, better fuel properties such as higher anti-knock quality can play a significant role in impacting the engine efficiency.

Historically, the anti-knock quality of gasoline fuels is described by two parameters, research octane number (RON) and motor octane number (MON), which are measured in standardized single cylinder naturally aspirated carburettor SI engines designed in the year of 1929, which are known as cooperative fuel research (CFR) engines [7–9]. Details of RON and MON test procedures are defined in the ASTM standards D2699-08 and D2700-08, respectively [10,11].

In the past 90 years since the introduction of CFR engines, internal combustion engines have developed significantly, driven by stringent fuel economy and emission standards [12–14]. Modern SI engines, especially the turbo-charged downsized designs tend to operate at relatively lower temperature but higher intake manifold pressure, resulting from the use of advanced hardware/technologies such as direct injection and charging intercooler [15]. In addition, the physiochemical properties of the reference fuels (iso-octane and *n*-heptane) used in CFR, called primary reference fuels (PRF), differ from gasoline available on the market, which consists of hundreds of hydrocarbons that have different properties such as boiling range, ignition delay, and octane sensitivity. Due to significant hardware and fuelling differences between the CFR and modern engines, the relevance of RON and MON to modern SI engines needs to be re-assessed.

The impact of RON has been studied by many investigators, and it is generally accepted that higher RON is beneficial to improving engine thermal efficiency [16–21]. However, the relevance of MON to modern gasoline engines is being challenged in the recent ten years [12,22–24]. It was found that, for some engine types and at some operating conditions, a fuel with a low MON for a given value of RON could be beneficial in reducing engine knock tendency [12,22,25–27]. To address the disconnect between CFR and modern engines, an octane index (OI) was proposed [1]:

$$\mathrm{OI} = \mathrm{RON} - \mathrm{K} \times (\mathrm{RON} - \mathrm{MON}) = \mathrm{RON} - \mathrm{K} \times \mathrm{S} \tag{1}$$

where K is a weighting factor depending solely on in-cylinder temperature and pressure history experienced by the end-gas prior to the onset of auto-ignition; S, the difference between RON and MON, is the octane sensitivity. A higher OI indicates that the engine is more resistant to knock. If K is negative, a fuel with a high octane sensitivity is beneficial to suppressing engine knocking [28].

The engine K value can be determined through either experiments or modelling. The experiment method relies on the correlation of an engine/vehicle performance parameter relating to fuels' auto-ignition properties such as knock limited spark advance (KLSA) and acceleration time with an RON and MON de-correlated fuel matrix. Details regarding the experiment method can be found in the literature [12,22,26,28–30]. For the modelling method, in-cylinder pressure data is required as an input, based on which the in-cylinder temperature is calculated. The crank angle of auto-ignition for a matrix of PRFs and toluene/n-heptane mixtures using the Livengood-Wu integral is calculated, and then the OI and K value of PRFs and toluene/n-heptane fuel mixtures are determined through the PRF calibration curve. Details about the modelling method can be found in research studies elsewhere [15,27].

There are a few studies available in the literature, focusing on the K value of SI engines/vehicles. Mittal and Heywood [21] found that K values of the vehicles produced between 1951 and 1991 became lower and even negative due to the use of advanced cooling and breathing techniques, and the replacement of carburettors with fuel injectors. They [31] tested fuels with various RON and MON in a single cylinder port fuel injection (PFI) SI engine under one bar intake manifold pressure. The experimental results showed that K value was negative. K had a strong dependence on the intake air temperature, engine speed, and intake charge pressure. Based on these findings, Mittal and Heywood [31] recommended modifying the octane rating tests to better bracket the knock limited operating conditions of modern SI engines.

Remmert et al. [27] studied the octane appetite and K value in a 4-cylinder DISI engine. Seven RON and MON decorrelated fuels were tested at several high load conditions. The impacts of external EGR, boost pressure, back pressure and lambda were investigated. They found that under high load conditions (approximately 20–30 BMEP), K value was in the range of −0.26 and −1.14. Davies et al. [15] investigated K value of several engines under high boost and EGR conditions. They found that K value was in the range of −0.86 to 0.5. Kalghatgi [29] reported that the averaged K value at full throttle conditions was −0.38 for 37 SI engines ranging from naturally aspirated to turbo-charged, and 1.2 L small engines to 2.4 L big engines. Orlebar et al. [30] conducted an octane sensitivity study on the model year 2007 Pontiac Solstice. They found that there was a clear negative correlation between charge pressure and K value.

Even though there are relevant publications available about the impact of fuel octane in spark-ignition (SI) engines, the RON and MON of the fuel matrices used in those studies were usually correlated, making the assessment of the individual contribution of RON and MON impossible. To address this knowledge gap, in this study six fuels were designed with independent control over RON and MON. The significance of RON and MON on the combustion characteristics were studied in a single cylinder DISI research engine. The experiments were conducted at the stoichiometric AFR with the engine speed of 1800 rpm and loads ranging from 4 and 20 bar IMEP using the fuel-specific optimum spark timing.

2. Experimental systems and methods

2.1. Engine and instrumentation

The experiment was conducted in an AVL single cylinder 4-stroke DISI research engine with 82 mm bore and 86 mm stroke, the setup of which is presented in Fig. 1. Its combustion system features a 4-valve pent roof cylinder head equipped with variable valve timing (VVT) systems for both intake and exhaust valves. The cylinder head was equipped with a central-mounted outward opening piezo direct injector. The spark plug was located at the centre of the combustion chamber slightly tilting towards the exhaust side. The compression ratio (CR) of this engine was manually adjusted by placing various sized metal sheets between the cylinder liner and the crankcase.

The engine was coupled to an electric dynamometer, which was able to maintain the engine at a constant speed (± 1 rpm) regardless of the engine power output. The engine was controlled via an IAV FI2RE management system. An AVL Indicom system was used for real-time combustion indication and analysis. A Siemens CATs system was used for data acquisition and recording, and it communicated with the IAV FI2RE and the AVL Indicom systems. The Siemens CATs system was also used for controlling air, fuel, coolant and lubricant conditioning equipment.

A Kistler pressure transducer was used for the in-cylinder pressure measurement, and it was installed in a sleeve on the intake and exhaust bridge. The cylinder pressure was collected via a charge amplifier (ETAS ES630.1). The sampling resolution was 0.1 crank angle (°CA) between −30 °CA and 70 °CA after top dead centre (ATDC), and 1 °CA in rest of the crank angles. Some key temperature and pressure measurement locations used are briefly labelled as 'T' and 'P' in Fig. 1.

The engine intake system was connected with an external air handling device, capable of delivering up to 3 bar boosted air. Air was first filtered, dried, and then delivered to a conditioning unit with a capacity of approximately 200 L, where air pressure and temperature were precisely close-loop controlled. Temperatures of fuel, coolant and lubricant were controlled by individual AVL conditioning systems. Fuel consumption was measured by an AVL fuel mass flow meter.

Download English Version:

https://daneshyari.com/en/article/6473839

Download Persian Version:

https://daneshyari.com/article/6473839

Daneshyari.com