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Investigation of gasoline containing GTL naphtha in a spark ignition engine at full load conditions

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ABSTRACT

Gas-to-liquid (GTL) naphtha can be used as a gasoline blend component, and the challenge of its low octane rating is solved by using ethanol as an octane booster. However, currently there is little knowledge available about the performance of gasolines containing GTL naphtha in spark ignition engines. The objective of this work is to assess full load performance of gasoline fuels containing GTL naphtha in a modern spark ignition engine. In this study, four new gasoline fuels containing up to 23.5 vol.% GTL naphtha, and a standard EN228 gasoline fuel (reference fuel) were tested. These new gasoline fuels all had similar octane rating with that of the standard EN228 gasoline fuel. The experiments were conducted in an AVL single cylinder spark ignition research engine under full load conditions in the engine speed range of 1000–4500 rpm. Two modern engine configurations, a boosted direct injection (DI) and a port fuel injection (PFI), were used. A comprehensive thermodynamic analysis was carried out to correlate experiment data with fuel properties. The results show that, at the full load operating conditions the combustion characteristics and emissions of those gasoline fuels containing GTL naphtha were comparable to those of the standard EN228 gasoline fuel. Volumetric fuel consumption of fuels with high GTL naphtha content was higher due to the need of adding more ethanol to offset the reduced octane rating caused by GTL naphtha. Results also indicate that, compared to the conventional compliant E228 gasoline fuel, lower particulate emissions were observed in gasoline fuels containing up to 15.4 vol.% GTL naphtha.

1. Introduction

The gas-to-liquid (GTL) Fischer Tropsch technology converts natural gas into high-quality liquid hydrocarbon products that would otherwise be made from crude oil [1]; therefore, the GTL technology reduces the dependence on crude oil. GTL products include GTL gasoil, GTL naphtha, GTL kerosene, GTL normal paraffin and GTL base oils [2].

GTL gasoil is currently used in compression ignition engines; therefore, it is also named as GTL diesel [3]. It consists almost exclusively of straight chain normal-paraffins and branched iso-paraffins; therefore, it has lower concentrations of aromatics, poly-aromatics, olefins. Additionally sulphur and nitrogen are lower than a conventional diesel. The low poly-aromatic content of GTL diesel are beneficial to reduce particulate matter (PM) emissions from diesel engines, providing more flexibility of controlling oxides of nitrogen (NOx) emissions by using exhaust gas recirculation (EGR) without compromising smoke emissions. The low sulphur content leads to a low tendency of deteriorating after treatment catalysts. The high cetane rating of GTL diesel is beneficial for the diesel engine combustion [3].

A wide range of research has been conducted on the combustion characteristics and emissions of GTL diesel using single cylinder and multi-cylinder engines, optical engines, and commercial vehicles under standard testing cycles, and real world driving conditions [4–14]. It has proved that the GTL diesel has the potential to deliver comparable engine performance and lower emissions to a conventional diesel without major engine hardware modifications. For example, Nishiumi and Clark et al. tested a GTL diesel on an in-line four cylinder diesel engines with a modified combustion chamber, a redesigned injection pattern, and a new EGR calibration [5]. Test results demonstrated that the combination of the GTL diesel and modified engine had the potential to reduce emissions whilst keeping the features of diesel engines such as low CO_2 emissions. The after treatment system for near-zero sulphur GTL diesel

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Nomenclature

AFR	air fuel ratio
ATDC	after top dead centre
BTDC	before top dead centre
CA	crank angle
CA10–90	crank angle interval between locations of 10% and 90% cumulative heat release
CA10–50	crank angle interval between locations of 10% and 50% cumulative heat release
CA50	crank angle at which 50% of cumulative heat release occurs
CA50–90	crank angle interval between locations of 50% and 90% cumulative heat release
CAD	crank angle degree
CO	carbon monoxide
COV	coefficient of variation
DI	direct injection
EGR	exhaust gas recirculation
FFT	Fast Fourier Transform
FID	flame ionization detector
GTL	gas-to-liquid
HoV	heat of vaporization
LHV	low heating value
THC	total hydrocarbon
IMEP	indicated mean effective pressure
MAPO	maximum amplitude of filtered and rectified in-cylinder pressure oscillation
MFB	mass fraction burn
MON	motor octane number
NOx	oxides of nitrogen
PFI	port fuel injection
PM	particulate mass
PN	particulate number
SI	spark ignition
rpm	Revolutions per Minute
RON	Research Octane Number
VVT	variable valve timing

fuel was optimised, resulting in improved the catalyst durability performance and higher NOx reduction efficiency because the catalyst can be designed to improve a low temperature activity and heat resistance. Clark et al. investigated effects of GTL diesel properties on diesel combustion [7]. Six GTL diesel fuels were formulated with various distillation characteristics and cetane number, and their spray behaviour, mixing characteristics, combustion and emissions were studied. Results showed that fuels with low distillation temperature and a high cetane rating led to reduction of hydrocarbon and particulate emissions, and combustion noise, which was explained by enhanced air/fuel mixing of the lighter fuel, high ignitability and short ignition delay.

Apart from engine combustion characteristics and emissions of GTL diesel fuels, some studies have been carried out focusing on the impact of GTL diesel fuels on fuel injection system. Lacey and Stevenson et al. evaluated the long-term performance of GTL diesel fuels in advanced common rail fuel injection systems [15]. Tests on engine testing cell, and electrically driven common rail pump hydraulic rig tests showed that the performance of GTL diesel was at least comparable to conventional hydrocarbon fuels and superior in a number of areas, and no deposits were produced on fuel injection system components even under severe operating conditions.

GTL naphtha, one of the products from the GTL process, mainly contains a light fraction of C4 to C11 hydrocarbons with a high proportion of straight chain paraffins. GTL naphtha is an alternative high-quality feedstock for plastics [2]. As a synthetic product, GTL naphtha has a consistent quality and contains near-zero sulphur and heavy metals, which makes it cleaner [2].

Searching for potential direct uses of GTL naphtha is of interest. Historically, it has not commercially been used in vehicles, because GTL naphtha has a low octane rating, making it unsuitable to be directly blended into conventional gasoline and be used in SI engines. The introduction of bio-ethanol as a blending component has made the octane rating of GTL naphtha a less limiting factor because ethanol has a high octane rating. However, currently there is little knowledge available about the performance of gasolines containing GTL naphtha in spark ignition engines.

In this study, four gasoline fuels containing up to 23.5 vol.% GTL naphtha, three of which were close to being EN228 compliant, were tested in an AVL state-of-art single cylinder gasoline research engine. A standard EN228 gasoline fuel was used as a benchmark for comparison. Two modern engine configurations, a boosted direct injection (DI) and a port fuel injection (PFI), were selected. The tests were conducted under full load condition in the engine speed range of 1000–4500 rpm. The focus was on the assessment of full load combustion characteristics and emissions of these new gasoline fuels with GTL naphtha. A comprehensive thermodynamic analysis was carried out to correlate engine data with fuel properties.

2. Experimental systems and methods

2.1. Engine and instrumentation

The engine used in this study is an AVL single cylinder 4-stroke spark ignition research engine, of which the specifications and setup are listed and presented in Table 1 and Fig. 1, respectively. 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 is equipped with a central-mounted outward opening high pressure piezo direct injector, and a low pressure PFI. The PFI injector is located in the intake manifold pointing towards intake valves. The spark plug is located at the centre of the combustion chamber slightly tilting towards the exhaust side.

Table 1
Engine specifications.

Parameters	Details
Combustion system	4-valve pent roof spark ignition
Displacement/bore/stroke	454 cm^3/82 mm/86 mm
Compression ratio	7–14 (variable)
Injection/ Injection pressure	Direct piezo injector/up to 20 MPa; PFI injection/0.45 MPa
Ignition system	Ignition coil
Engine management system	IAV GmbH – FI2RE
Maximum boost pressure[a]	0.3 MPa
Maximum engine speed	6400 rpm

[a] The maximum boost pressuer the engine can take differs, largely depending on the engine compression ratio. The maximum boost pressure (0.3 MPa) stated in this table is for compression ratio of approximately 7.5:1.