Fuel 111 (2013) 305–315

Contents lists available at SciVerse ScienceDirect

Fuel

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

Review article

Experimental investigations on high octane number gasoline formulations for internal combustion engines

Tarcisio Cerri *, Gianluca D'Errico, Angelo Onorati

Department of Energy, Politecnico di Milano, via R. Lambruschini 4, 20156 Milano, Italy

HIGHLIGHTS

- Different research gasoline formulations for SI engine have been investigated.
- The fuels tested were characterized by different contents of olefins and oxygen.
- High octane gasolines show different behavior in the cycle combustion variability.
- No significant power increase was found by using fuels with high octane number.
- The MON better characterize the octane requirement at high engine speeds and loads.

ARTICLE INFO

Article history:
Received 3 May 2012
Received in revised form 22 March 2013
Accepted 25 March 2013
Available online 17 April 2013

Keywords:
Gasoline formulations
Oxygenated compounds
Cyclic combustion variability
Knock

ABSTRACT

The attempt to achieve higher and higher levels of specific power output and efficiency has increased the complexity of the design process of both the engine and its management system. Among the different issues, it is also necessary to take into account the chemical and physical characteristics of the available fuels. In order to study the behavior of some gasoline formulations characterized by a high octane number, the authors have carried out an experimental activity to understand how each fuel sample could improve the performances of a modern naturally aspirated SI (spark ignition) engine for passenger cars. The new fuel formulations were characterized by different contents of olefins and oxygen, the latter through the presence of oxygenated compounds like ethyl tert-butyl ether (ETBE) or methyl tert-butyl ether (MTBE). The experimental campaign consisted in measurements of the maximum brake torque (MBT) curve up to knock onset and the corresponding knock intensity, at wide open throttle (WOT) and partial load operating conditions, for each tested gasoline sample. The results of the data analysis show that the evaluation of the enhanced characteristics of a gasoline cannot be done by considering only the increase of the knock limit. Although a gasoline is generally labeled only by its RON (Research Octane Number), it can extend the benefits due to particular chemical formulation from full load up to part load conditions and, may be, in transient situations, as pointed out in this work. A naturally aspirated SI engine, under steady operation and fueled by high octane number gasolines, cannot provide a higher power output at WOT condition only by modifying the spark timing, if this engine has already been correctly optimized by the manufacturer before introducing it on the market. As a result, to achieve higher levels of power output it is necessary to modify the compression ratio, the Variable Intake System (VIS) and Valve Timing (VVT) strategies and so on, in order to exploit the high octane number offered by the new gasolines tested. Moreover, the analysis of the experimental data has also confirmed that the Research Octane Number (RON) index is less important than the Motor Octane Number (MON) at high engine speeds and loads, useful to characterize the octane requirement for modern engines. Furthermore, a standard deviation analysis has been conducted on the BMF (Burned Mass Fraction) parameter to understand if the different characteristics of gasolines could give advantages in terms of reduction of the CCV (Cyclic Combustion Variability). The results of the data analysis showed that the fuel

Abbreviations: AFR, air-fuel ratio; BMEP, brake mean effective pressure; BMF, burned mass fraction; BSFC, brake specific fuel consumption; BSP, brake specific power; CAD, crank angle degree; CCV, cyclic combustion variability; CFR, cooperative fuel research; CV, coefficient of variation; DAQ, data acquisition system; ECU, engine control unit; EMS, engine management system; ETBE, ethyl tert-butyl ether; IMEP, indicated mean effective pressure; MBT, maximum brake torque; MON, motor octane number; MTBE, methyl tert-butyl ether; PFI, port fuel injection; RON, research octane number; rps, revolution per second; UEGO, universal exhaust gas oxygen; VIS, variable intake system; VVT, variable valve timing; WOT, wide open throttle.

* Corresponding author. Tel.: +39 02 2399 3819.
E-mail address: tarcisio.cerri@polimi.it (T. Cerri).

0016-2361/$ - see front matter
http://dx.doi.org/10.1016/j.fuel.2013.03.065

formulations with higher content of oxygenated compounds exhibit a better behavior, highlighting a smaller CV (Coefficient of Variation) especially when reducing the load. This aspect could be considered one of the possible reasons of an improvement of the vehicle drivability.

Contents

1. Introduction

The optimal formulation of gasoline fuel for spark ignition engines, to guarantee the best performances and minimal pollutant emissions, has always been one of the relevant challenges in the long history of this well established technology. Many successful steps and milestones in the evolution of I.C. engines were related to the continuous improvement of the fuel chemical composition and physical characteristics. Modern engines can reach high performances and comply with stringent emission limits, also thanks to the high quality of fuels and lubricants. Several studies have been carried out during the last decades, to understand how different compounds (e.g. ethers) or a different percentage of typical hydrocarbon families (olefins, aromatics, etc.) can improve the knock resistance [1,2] for SI engine applications. The addition of oxygenates to gasoline can improve the fuel volatility, enhance combustion and decrease the carbon monoxide and hydrocarbon emissions [3].

On the other hand, there is less information about the existing correlation between the fuel formulation and the occurring cyclic variability. The optimal "knock limited" spark timing is chosen taking into account cycle-to-cycle variations [4,5] and the fact that an excessive level of variability can have a negative impact on the vehicle drivability, leading to increased levels of fuel consumption and emissions. Experimental and theoretical studies on cyclic combustion variability were mainly focused on lean mixture operation and low load conditions [6].

Different strategies are typically implemented in the electronic control management system to avoid knock [7]. Both experimental and numerical studies are performed in a design stage, to understand the development of abnormal combustion and prevent it [8]. The experimental analysis is based on the accelerometer signal, which is processed by the ECU to recognize the presence of knock by comparing it with a reference noise, which is considered normal. In this case the ECU reduces the spark timing until the knock phenomenon disappears. Also the equivalence ratio can be modified simultaneously or separately, but the first method is more effective to eliminate the abnormal combustion, so it is typically adopted. In general, to achieve a better thermodynamic efficiency and a higher power output, the engine mechanical and volumetric efficiency need to be increased. Engineers typically design new engines taking account not only of these aspects, but also of the characteristics of the fuel which will be used, depending on the final market of the vehicle. For this purpose, they experimentally establish the octane requirement of the engine, checking that it is compatible with the available octane number of the fuels on the market.

Moreover, knock limits the performances of turbocharged SI engines much more than those of naturally aspirated units. Engine manufacturers currently focus their research on the "downsizing" concept, which consists of replacing a naturally aspirated engine with a turbocharged power-train with less displacement. Hence, several research centers and oil refiners are carrying out their studies on fuels considering this aspect [9,10]. Nevertheless, on the market there are still a lot of four stroke, naturally aspirated engines, having medium–high performances achieved by means of high values of IMEP (around 1.35 MPa) at medium–high engine revolution speeds. This good performance demands a series of characteristics (e.g. variable geometry intake system, variable valve timing, etc.) which allow reaching the aforementioned IMEP level.

To understand if this type of engines could have a benefit by using research oxygenated gasoline with a high octane number, an extensive experimental activity was carried out in the laboratories of Politecnico di Milano. The aim was to verify if new gasoline formulations (different from the eurosuper-type/RON95) could give either a higher power output or other possible advantages in terms of performances.

The tested research gasolines were mainly characterized by a high octane number and different content of olefins and oxygen, due to the presence of oxygenated compounds like ETBE or MTBE, with respect to the typical commercial gasoline. The available fuels were classified in five different samples, among which there was also the commercial fuel (RON95), which was used by the manufacturer to optimize the engine before introducing it on the market. The main characteristics of the tested fuels are reported in Table 1, in which the commercial fuel was labeled as "reference fuel" E. All the available samples of fuel (A–E) are characterized by the same value of both LHV (Lower Heating Value), equal to 42.5 MJ/kg, and specific mass, close to 750 kg/m^3.

One of the goals of this research activity was to understand if higher levels of power output could be achieved only by modifying the spark timing, using the tested gasoline samples. A secondary aspect was to verify, directly on a modern engine, which index better characterizes the knock resistance of a gasoline and, as a consequence, its impact on the octane requirement of the engine. Similar investigations have been conducted in the last years to exploit these aspects [11,12]. It is well known that the primary index to quantify this characteristic is the RON, determined in the laboratory by using the Cooperative Fuel Research (CFR) engine, under