

Impact of Fuel Properties on the Performances and Knock Behaviour of a Downsized Turbocharged DI SI Engine – Focus on Octane Numbers and Latent Heat of Vaporization

Jean Milpied and Nicolas Jeuland
IFP

Alexandre Marchal
RENAULT

Gabriel Plassat
ADEME

Pierre Schmelzle
TOTAL

Sabine Guichaous and Nathalie Dioc
PSA

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ABSTRACT

Facing the CO₂ emission reduction challenge, the combination of downsizing and turbocharging appears as one of the most promising solution for the development of high efficiency gasoline engines. In this context, as knock resistance is a major issue, limiting the performances of turbocharged downsized gasoline engines, fuel properties are more than ever key parameters to achieve high performances and low fuel consumption's levels.

This paper presents a combustion study carried out into the GSM consortium of fuel quality effects on the performances of a downsized turbocharged Direct Injection SI engine. The formulation of two adapted fuel matrix has allowed to separate and evaluate the impacts of three major fuel properties : Research Octane Number (RON), Motor Octane Number (MON) and Latent Heat of Vaporization (LHV).

Engine tests were performed on a single cylinder engine at steady state operating condition. The engine corresponds to a downsized GDI SI engine with a displacement of 300cm³ and allows IMEP up to 30bar according to the engine speed. For each tested fuel, knock limitations have been evaluated at various engine speed.

Through the development of adapted methodologies for extended results analysis, contributions of RON, MON and LHV to knock resistance were isolated, evaluated and compared. This study confirms and weights the striking role of high RON values and the positive influence of the "cooling effect" linked to high LHV values. However, no clear impact of the MON was noticed.

Considering the double knock resistance action of ethanol, attention was particularly paid to ethanol blend fuels. In the case of a 20%v ethanol blend, the "cooling effect" brings from 30 to 60%, depending on engine speed, of the total knock resistance increase, compared to gasoline base fuel.

INTRODUCTION

In the frame of more and more stringent local and global emissions regulations, the development of advanced powertrain solutions able to propose both low CO₂ emissions and low pollutants emissions respecting future Euro5 levels is compulsory.

In the field of SI engines, several key technological solutions are emerging and amongst them, engine deep strong downsizing appears as one promising answer to future challenges. Indeed, the coupling of turbocharging, engine downsizing and direct injection leads to a large increase of SI engine efficiency and so to an interesting gain in terms of CO₂ emissions [1].

However, one major issue to fully used the down sizing potential remains their higher knock sensitivity [2]. Nevertheless, one way to overcome this limiting point can be the adaptation of gasoline fuel formulation [3]. By its antiknock properties, gasoline fuel and its blends with ethanol appears as a key tuning parameter to allow an enlarged operating range of downsized SI engines.

In this context, the role that fuel properties, and particularly antiknock participating properties, can play to improve downsized SI engines behavior has to be precisely evaluated. This point stands as the main topic of this study.

Moreover, the study of fuel formulation impacts has to be performed keeping a global coherence with the general fuels evolution and so, with the increasing incorporation of bio-ethanol in gasoline fuels that is currently occurring worldwide [4]. Bio-ethanol and ETBE rates were tested in this study all the more so since ethanol and ETBE molecules present very interesting antiknock properties.

The impacts of two types of fuel antiknock properties have been evaluated.

- Direct antiknock properties : fuel RON and MON values
- Indirect antiknock property : the Latent Heat of Vaporization of fuel (LHV)

LHV is classically suspected to have an indirect antiknock property by cooling the air-fuel mixture when fuel evaporates during the intake stroke in a DI SI engine and so by thermally postponing the fuel auto-ignition in knock conditions. This impact is classically called "cooling effect" [5,6].

Regarding "cooling effect", ethanol impact is of great interest as ethanol presents an high LHV value that would potentially enlarge the impact of injected ethanol blend fuels [7,8,9].

Even if the roles of RON, MON and LHV on knock occurrence have already been studied [3,10], the interest of this study is to propose adapted experimental fuel matrix and methodologies leading to the separated evaluation of all of these three parameters impacts on a next generation downsized turbocharged Direct Injection SI engine.

Two fuel matrix have been formulated on purpose and tested on a single cylinder downsized turbocharged Direct Injection SI engine. First, these twelve fuel properties are detailed. Second, results of fuel impacts on the knock limitations loads reached are presented. In a following part, methodologies leading to the separated evaluation of RON, MON and LHV impacts on knock occurrence are described and the resulting evaluations are analyzed. Finally, results are discussed and practically applied to the case of ethanol blend fuels.

EXPERIMENTAL CONDITIONS

ENGINE CONFIGURATION

The study was led on an IFP downsized single cylinder engine on a stationary test bench (Table1).

Type	Prototype downsized single cylinder SI engine
Valves	4
Displacement (cm3)	301
Bore x stroke (mm)	69.0 x 80.5
Compression ratio	9.5 : 1
Injection	Gasoline Direct Injection Multi-hole injector
Injection pressure (bar)	120
Combustion type	Homogeneous and stoichiometric conditions
Turbo-charging	Sonic throttle

Table 1 : Engine configuration

The single cylinder engine was equipped with a fast pressure transducer (KISTLER 6043A60) associated with a charge amplifier (KISTLER 511) for combustion chamber pressure measurements.

FUEL MATRIX

Two fuel matrix were specifically designed and formulated to explore the three fuel parameters impacts : RON, MON and LHV.

RON-MON fuel matrix

Six fuels were formulated in order to explore the RON and MON axis respecting common criteria :

- sulfur content < 50ppm
- vapor pressure in between [450 – 600] mbar
- no oxygen content.

These properties, including neat heating values (NHV) and specific gravity, are listed here below with reference fuel characteristics.

fuel name	RON	MON	NHV	specific gravity (15°C)	Sulfur	[O]
-	-	-	kJ/kg	kg/m3	ppm	%vol
Ref.	95.6	86.5	43047	750	9.3	0.97
A	91.6	81.6	39904	586	23	<0.17
B	95.5	85	42819	547	37	<0.17
C	94.5	88.1	43301	569	5	0.06
D	98.1	87.8	40644	527	5	0
E	98.2	85.5	43102	606	19	<0.17
F	100.4	90	42560	556	2	0

Table 2 : RON-MON fuel matrix

The interest of the RON-MON fuel matrix is to contain fuel couples with the same RON but with different MON values :

- (B, C) for RON = 95
- (E, D) for RON = 98

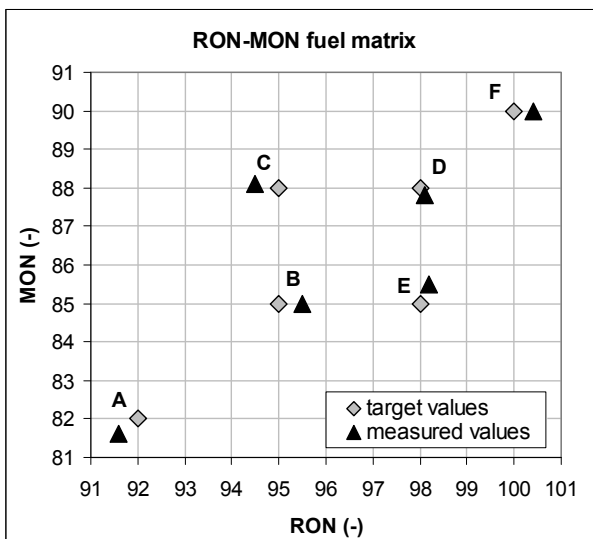


Figure 1 : RON-MON fuel matrix

Latent Heat of Vaporization (LHV) fuel matrix

Fuel formulation

The LHV fuel matrix was composed of five new fuels plus fuel F from the RON-MON fuel matrix. These five new fuels were formulated based on the RON-MON matrix fuels with three objectives :

- to reach a final RON value set to 100 for all fuels
- to explore the LHV impact at equal RON value
- to explore the oxygen impact at equal RON and LHV values

Formulation levers where then the use of ethanol and ETBE as blend compounds.

- Ethanol brings RON, LHV and oxygen
- ETBE brings RON and oxygen

So, the 5 new fuels were formulated so as to respect the fixed formulation criteria : final RON = 100.

- fuel G = fuel A + ethanol
- fuel H = fuel A + ETBE
- fuel I = fuel B + ethanol
- fuel J = fuel D + ethanol
- fuel K = fuel B + ETBE

Fuel properties and "cooling power" calculation

To specifically evaluate the "cooling effect" of each formulated fuel, the calculated "cooling power" value is proposed. We defined the "cooling power" value as the energy taken from the stoichiometric air-fuel mixture by the vaporization of the injected fuel. Its calculation formula is then :

$$\text{"cooling power"} \text{ (kJ / kg air)} = \text{LHV} / (\text{A/F})$$

where,

LHV = Latent Heat of Vaporization (kJ/kg) .

A/F = stoichiometric mass Air / Fuel ratio (kg/kg)

The LHV values of blend fuels where calculated from LHV values of the blending components and their volumetric content in the blend, using a linear approach. This assessment is available for blends up to 20 %v of ethanol [8].

The LHV values of the blending components used for calculation are :

- for gasoline : LHV = 335 kJ/kg
- for ethanol : LHV = 910 kJ/kg
- for ETBE : LHV = 290 kJ/kg