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Full Length Article

Impact of injection strategy and GTL fuels on combustion process and performance under diesel engine start

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HIGHLIGHTS

- Cycle to cycle engine start has been studied under hot and relative cold thermal conditions.
- Diesel and paraffinic fuels have been tested under engine start and both thermal conditions.
- Injection strategy has been modified under engine start with three fuels tested.
- Injection strategy and cetane number have impact on indicated efficiency under engine start.
- Paraffinic fuels have impact on efficiency under start of engines with delayed injection strategy.

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ABSTRACT

The impact of three fuels (a diesel fuel without biodiesel and two Fischer Tropsch low temperature gas to liquid paraffinic fuels from natural gas) on the indicated engine performance and the timing of the combustion process under the engine start has been studied by means of cycle to cycle thermodynamic diagnosis during the first 5–6 cycles along the whole starting process. The study was carried out varying the beginning of the start of pre-injections at different thermal conditions of the engine. In all cases exhaust gas recirculation valve was closed. Both, the rate of apparent heat release and the indicated efficiency, were mainly used as comparative parameters. The work was carried out on a Nissan Qashqai light duty diesel vehicle equipped with a Kistler Kibox thermodynamic analyzer. Piezoelectric in-cylinder pressure sensors were mounted on each engine cylinder. This work demonstrates the relevance of fuel used during the engine tuning. The efficiency of GTL fuels was better when delayed strategy was tested. Compared to diesel fuel, there is potential for improving the benefits of GTL fuels on engine performance.

1. Introduction

Among the transient processes which take place during vehicle driving, engine starting is becoming one of the most important. A low in-cylinder mean temperature affects negatively the starting process [1,2]. This temperature is highly dependent of factors such as the ambient temperature and the engine compression ratio. In order to reduce pollutant emissions, mainly nitrogen oxides (NOx) and particulate matter, modern diesel engines present lower compression ratios and, consequently, lower in-cylinder pressure and temperatures, leading, together with relatively cold ambient temperatures, to a decrease of fuel volatility that worsens the air-fuel mixing process and the fuel ignition during the start [3]. Moreover, during the start, the premixed phase of combustion is enlarged and noise is enhanced. In other ways, due to the high gradient of temperatures between the cold engine in-cylinder walls and combustion gases, the heat transfer through cylinder walls increases as well as an increase of fuel injected is also observed. If other effects are added, such as the increase of oil viscosity with the subsequent increase of mechanical losses, the high probability of misfiring or the low efficiency of oxidation catalysts and the injection strategy, it can be concluded that the engine start will present high combustion instability and emissions [1,2,4]. This has led the regulations to include this transient process in their light vehicle certification cycles. In both the New European Driving Cycle (NEDC) and the US Federal Test Procedure (FTP-75), the cold start implies a coolant temperature over 20 °C, i.e., the cold start occurs at room temperature (about 22 ± 2 and 20–30 °C, respectively) [5–7].

Different strategies focused on the lubricant or the catalytic converter have been suggested [1]. In addition, in order to promote ignition especially when the start occurs at very low temperatures, the temperature of the air entering the combustion chamber can be

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increased with intake heaters or glow plugs [3]. On the other hand, new injection strategies can improve the start-ability without an increase of fuel mass injected. Multiple injection systems reduce the ignition delay softening the premixed combustion phase and reducing combustion noise [8]. Moreover, a decrease of white smoke and NOx emissions can be also observed [9]. Payri et al. [10], using a single cylinder engine fueled with pure diesel, verified that the use of one or two pre-injections together with a main injection increases the indicated mean effective pressure and, therefore, the indicated efficiency. At very cold conditions, the start-ability and combustion stability after start was improved when two pre-injections were used. Additionally, the dwell time was found to be the most important parameter affecting the combustion behavior. Osuka et al. [9] also found that split injection systems improved the start-ability not only at cold temperatures but also at room temperatures close to the relative cold start under certification cycles.

Finally, the use of additives or even alternative fuels with high cetane number can be other solution. Biofuels like biodiesel or bioethanol have been widely used due to, on one hand, their renewable nature (surrogate of fossil fuels) and, on the other hand, their emissions advantages [11,12]. Low quantities of biodiesel blended with diesel don't increase the fuel consumption during the start and start-ability is not affected [13]. However, the higher initial boiling point and viscosity of pure biodiesel, which leads to poor fuel spray atomization and evaporation, worsen the fuel-air mixing process and, consequently, the starting process when the engine is not warm [11]. The use of biodiesel decreased smoke opacity and particle concentration, high NOx emissions were observed [13]. Similarly to biodiesel, alcohol blends, mainly bioethanol or butanol blends, also show problems during the start mainly due to their very low cetane number, specifically in terms of an increase of the start time and emissions [12]. Therefore, this behavior brings to light the need of optimization of engine parameters when biofuels are used as fuel.

New paraffinic fuels such as hydro-treated vegetable oil (HVO) or Gas-To-Liquid (GTL) are nowadays being investigated. Although without oxygen content in their composition, they present a very high cetane number and, consequently, small ignition delay. It enables low engine compression ratios, which together with an optimization of the injection strategy as a function of the engine operating mode, lead to low emissions [14,15]. Moreover, a stable combustion during a cold start (at room temperature of −20 °C) was verified by Schaberg et al. [14].

In this study, in the line of works related to the optimization of engine calibrations using GTL fuels presented by researchers from Sasol Co. [14,15], the behavior of a Nissan Qashqai light duty diesel vehicle under relative cold start has been studied and compared to warm start, when the engine is fueled with a GTL from natural gas and the injection strategy is modified. The indicated engine performance and the timing of the combustion process when advancing and delaying the pre-injections were also compared to those obtained with pure diesel without biodiesel which was used as reference fuel.

2. Experimental installation and procedures

2.1. Engine and equipment

The experimental work was carried out using a NISSAN Qashqai 2.0 dCi light-duty vehicle equipped with a four-cylinder and four-stroke diesel engine (model M1D). The vehicle used is commercially tuned according to Euro 4 regulation. However, for this work the vehicle was equipped by manufacturer with the same emission control devices as Euro 5 engines. Active technologies such as common rail injection system with split injection, cooled exhaust gas recirculation (EGR) and variable geometry turbocharger (VGT) with intercooler were included in this version of engine. As passive technologies for emission control of this version of engine were included the following: diesel oxidation catalyst (DOC) and regenerative wall flow type diesel particle filter (DPF). The main characteristics of the engine are shown in Table 1.

In this work, the engine was tested without glow-plugs. This is the main reason for deciding do not to test the vehicle with temperatures lower than 15 °C. This temperature is high enough to see the effect of both strategy and fuels without starting aid system. In each glow-plug hole a piezoelectric in-cylinder pressure sensor model Kistler model 6056AU20, without cooling, was mounted. Current probes were used for registering the current of energizing of fuel injectors while a crank angle sensor was used to determine the angle position of the first piston (furthest cylinder from the flywheel). An integrated calibration and acquisition system (INCA) with an ETAS ES 591.1 hardware (www.etas.com) were used for the communication and management of the opened electronic control unit (ECU). All this equipment was coupled to a Kistler Kibox system which allows the determination of different thermodynamic parameters related to injection and combustion processes such as: indicated mean effective pressure (imep), start of energizing (SoE), ignition delay (ID), start of combustion (SoC), apparent heat release (AHR) and the end of combustion (EoC), among others. A detailed description of thermodynamic calculation model, included in the Kistler Kibox system, has been previously presented by Armas et al. [16]. Fig. 1 shows a sketch of the complete experimental installation mounted on the vehicle.

Table 1
Main engine characteristics.

Parameter	Value
Cylinders	4
Total swept volume (cm^3)	1.994
Bore (mm)	84
Stroke (mm)	90
Maximum rated power (kW)	110 at 4.000 min^{-1}
Maximum rated torque (Nm)	323 at 2.000 min^{-1}
Valves per cylinder	4
Compression ratio	16:1
Total number of pre-main-post injections	2-1-2

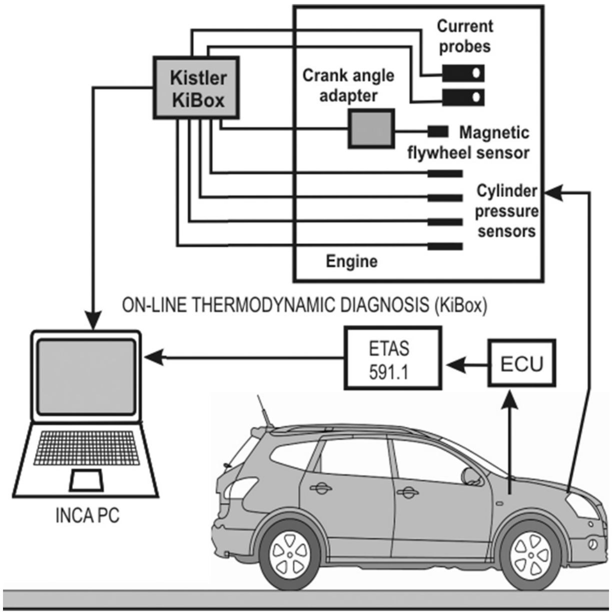

Fig. 1. Scheme of the experimental installation.