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Impact of Gas To Liquid and diesel fuels on the engine cold start

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HIGHLIGHTS

- Gas To Liquid and diesel fuels were tested under cold engine start conditions.
- A methodology to evaluate different parameters from thermodynamic diagnosis has been developed.
- Parameters derived from on-line thermodynamic diagnosis have been studied.
- Clear effect of the engine coolant temperature on the rate of apparent heat release has been observed.
- The effect of cetane number is notable at low cold start temperatures.

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ABSTRACT

Low ambient temperatures during start process have a notable influence on the combustion process. A methodology to study parameters as indicated mean pressure and rate of heat release, obtained using on-line thermodynamic diagnosis under cold start, was developed in this work. For this study, the correction of the pressure level from the first cycle measured has been made. Two ambient temperatures (20 °C and −7 °C) and two engine temperatures (20 °C and 70 °C) were selected for this study. A Gas To Liquid fuel and two diesel fuels (one of them with 5.8% of biodiesel) were tested in a Euro 4 diesel light-duty vehicle. Values of indicated mean pressure were higher during the first thermodynamic cycle than those corresponding to idle conditions with all fuels tested. Low engine temperature (20 °C) makes the combustion of fuel during pre-injection difficult and, consequently, only one peak of apparent heat release was registered. Fuel pre-injected burns together with fuel injected during the main injection. Besides, the effect of high cetane number of GTL is evident at low ambient temperature because its combustion takes place some degrees before compared to both diesel fuels tested.

1. Introduction

Starting process is one of the most critical transient processes of Diesel engines because of the drastic load increase in a short period. Levels of noise, fuel consumption, and pollutant emissions are higher than other transient sequences tested in engines [1,2].

The high level of emissions during start has increased the interest of the effect of cold temperatures during this process due to the need to fulfill the standard emissions established for vehicle certification since this process was included in homologation cycles (New European Driving Cycle (NEDC) and FTP US Federal Test Procedure (FTP-75), etc.). Under NEDC tests, cold start process is considered when the engine coolant and ambient temperatures are the same, being 20 °C the minimum in the range of temperatures established. Low ambient temperatures lead to an increase of oil viscosity, reduce the gas temperature at the start and the end of compression process [3] and have an influence on the duration of this stage [4]. Additionally, regarding fuel properties, low temperatures make difficult its atomization, evaporation and the mixture with air. All these effects promote an incomplete combustion with the consequent increase in pollutant emissions. Some authors have obtained up to seven times more particulate matter [5,6] or even 100 times higher the unburned hydrocarbons compared to warm conditions.

The possible reduction of ambient temperature for the future homologation cycles would mean an additional difficulty regarding starting the process. The notable differences on pollutant emissions obtained under real driving cycles on those of certification cycles are forcing to modify the latter to be more representative

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of real driving conditions (Worldwide harmonized Light vehicles Test Procedure, WLTP). In this sense, the temperature of certification tests may also be reduced (around −7 °C) to be closer to temperatures of winter in different countries in Europe.

Different authors have studied the effect of a cold start in performance and emission on a diesel engine, with different fuels (mainly biodiesel fuel). Temperatures under cold start tests are different in function of the work published. Roy et al. [7] tested different biodiesel-diesel fuel blends at temperatures around 20 °C–25 °C, obtaining reductions in pollutant emissions with biofuels but once idle conditions were reached (testing three different idle engine speed values). Armas et al. [8] studied the effect of different alcohol-diesel blends on performance and emissions during a cold start at temperatures around 20 °C. Some works were tested at cold temperatures (lower than 20 °C). Broatch et al. [9] examined different biodiesels (−10 °C, −5 °C and 0 °C) to evaluate the stability of the starting process and smoke opacity focusing the study on the variation of Cold Filter Plugging Point (CFFP). In this work, they concluded that the increase of viscosity at low temperature is a critical effect to ensure the stability of the starting process using biodiesel. Randazzo and Sodré et al. [10] evaluated biodiesel-bioethanol-diesel blends at −5 °C and their results indicated the cold start time increased when bioethanol content was higher.

The effect of other alternative fuels as Gas To Liquid (GTL) on performance and pollutant emissions has been also studied, but mainly under stationary operating modes. Some studies indicated the reduction of pollutant emissions when GTL is used, mainly PM and smoke opacity, Justified by the lack of aromatic compounds (compared to diesel fuel) [11,12]. Gill et al. [13] indicated that, the lower distillation curve and the improvement in atomization, favors a faster evaporation and the more complete mix with air and, consequently, less pollutant emissions.

Abu-Jrai et al. observed [14] less premixed combustion phase and, consequently, lower maximum heat release because of higher cetane number of GTL. For this reason, NOx emissions with this alternative fuel were lower than those of diesel fuel. However, the bibliography related to the effect of this alternative fuel on cold start process is limited. Armas et al. [15] tested GTL fuel, in an engine test bench, during cold (20 °C) and warm start and reduction of smoke opacity, PM, CO and THC emissions, but a slightly increase of NOx, were obtained during cold start. Also, these authors [16] have evaluated the effect of different injection strategies on performance and combustion, using two GTL fuels (different Cold Filter Plugging Point values) in the same vehicle used in this work.

One of the most useful tools to know how this process takes place is the thermodynamic diagnosis [17,18]. Parameters as in-cylinder pressure and apparent heat release allow to evaluate the evolution of this process and, consequently, provide an explanation about performance and emissions produced. Few studies have been carried out about the thermodynamic diagnosis or combustion characterization during cold start process. Pastor et al. [19] and Desantes et al. [20] commented that injection strategies with low pressure and short duration favor the combustion of pilot injection during cold star but, after that, during main combustion, high pressure is necessary in the rail. Wang et al. [21] indicated that low temperatures delay the start of atomization.

In this work, the effect of a GTL fuel and two diesel fuels on the behavior of the starting process at low temperatures has been studied using on-line thermodynamic diagnosis. To make this study, a methodology to evaluate different parameters of thermodynamic diagnosis, using a Kistler Kibox device, has been developed.

2. Experimental facilities and test fuels

2.1. Engine and equipment

Fig. 1 shows the scheme of the experimental installation. The vehicle used for this work was a Euro 4 NISSAN Qashqai 2.0 dCi, direct injection diesel engine four-cylinders, four-stroke, turbocharged, intercooled with common rail and split-injection. This vehicle was tuned to fulfill Euro 4 standard, but it was equipped with different devices as those engines that fulfill Euro 5 (cooled high-pressure loop exhaust gas recirculation (HP-EGR) and regenerative wall flow-type diesel particle filter (DPF)). Characteristics of vehicle, used in previous works [22], are detailed in Table 1. Using INCA PC software and the ETAS ES 591.1 hardware it is possible the communication with Electronic Control Unit (ECU).

Starting test at cold temperatures were carried out using a climatic chamber that allows the control of ambient temperature from −20 °C up to 35 °C. To get a stable temperature in engine (different fluids as oil, coolant, etc.) vehicle was soaked during 8 hours. The soaking time required for maintaining stable temperatures in the engine fluids (oil, coolant, fuel and battery electrolyte) before tests depended on the set-up temperature level: it was about 8 h for tests at −10 °C.

Thermodynamic diagnosis allows calculating different parameters as indicated mean effective pressure, the start of combustion, apparent heat release rate, etc. Equations used for determining these parameters are detailed in Armas et al. [23]. The software of Kistler Kibox system, for the different calculations, needs the following signals: a) the in-cylinder pressure (measured by Kistler piezoelectric sensor model 6056AU20, coupled to four cylinders, b) the current of energizing of the fuel injector and c) the crank angle sensor signal.

The engine start was studied with different fuels. For all the fuels tested, three repetitions were carried out in order to quantify the variability of the tests.

2.2. Fuels tested

In this study, the three fuels tested are detailed below.

- Diesel fuel similar to that supplied in Spanish petrol stations (with 5.8% of biodiesel in volume basis) marketed by CEPSA Co. and noted as Diesel wB.
- Neat Diesel (without biodiesel), prepared by REPSOL Technology Centre, and denoted as Diesel.
- Gas To Liquid (GTL) fuel obtained from a Fischer-Tropsch process at Low Temperature, provided by SASOL Co.

The main properties of fuels tested are shown in Table 2.

3. Test methodology

3.1. Introduction

The engine start is a critical and complex process, and the definition of its phases depends on each type of engine [5]. The criteria followed in this work, considering the time evolution of the engine speed for defining the main phases of the engine start, are detailed below and presented in Fig. 2.

- *Phase 1 or Cranking:* An electric starter moves the engine crankshaft and its pistons. During this phase, there is no injection nor combustion process. In this phase, the engine must reach around 250 min^{-1}.