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Assessment of the effect of low viscosity oils usage on a light duty diesel engine fuel consumption in stationary and transient conditions

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ABSTRACT

Regarding the global warming due to CO_2 emissions, the crude oil depletion and its corresponding rising prices, OEMs are exploring different solutions to increase the internal combustion engine efficiency, among which, the use of Low Viscosity Oils (LVO) represents one attractive cost-effective way to accomplish this goal. Reported in terms of fuel consumption, the effect of LVO is round 2%, depending on the test conditions, especially if the test has taken place in laboratory or "on road" conditions. This study presents the fuel consumption benefits of a commercial 5W20, compared against higher SAE grade oils, on a light duty diesel engine, when it is running under motored test, stationary fired test and the New European Driving Cycle (NEDC).

1. Introduction

It is a well-known fact that Green House Gases (GHG) emissions from the combustion process which takes place during the working cycle of the Internal Combustion Engines (ICE) contributes significantly to global warming[1–3]. Additionally, the sustained raising price of the fossil fuels and crude oil's depletion increases the necessity to improve the ICE efficiency [4–6]. Furthermore, fuel economy and CO_2 regulations have been imposed in several countries in the recent years both for light duty and heavy duty segments and is expected that these regulations will be more severe in the future [7,8].

To face these challenges, OEMs have been working on diverse techniques to reduce fuel consumption and CO_2 emissions which include direct injection, variable valve actuation, downsizing, stop-start engines, the use of bio-fuels, and so on. Among these proposed powertrain efficiency enhancing techniques, the use of Low Viscosity Oils (LVO) has been studied as a cost-effective way to reduce fuel consumption, based on the principle that the less viscous the lubricant oil is, the less engine power is required to reach some specific operational conditions [9–11]. Tribologically this assumption is valid when the lubricated interface is under a hydrodynamic regime, which takes place when the lubricant layer thickness is large enough to prevent contact between the moving parts, being the lubricant's inner shear strength the only resistance which goes against the relative movement. Consequently by reducing the oil's viscosity, the magnitude of this resistance tends to diminish leading to reduced fuel consumption. Nonetheless, the viscosity reduction approach must be done carefully when engine oil is being formulated cause less viscosity implies lesser oil thickness, moving the lubrication regimes towards mixed and boundary zones where wear could be increased. It has to be mentioned that the use of LVO does not require additional engine modifications, hence the cost-benefit ratio is wider than for other techniques.

However, the reported benefits of fuel consumption reduction of LVO, in terms of percentage, vary significantly both for the light and the heavy duty segment, ranging from 0.5% to 3.5% depending on many factors like the test nature (i.e. chassis dyno, engine bench test fired, engine test motored, stripping test and so on), engine's constructive characteristics (i.e. valve train system, number of cylinders, injection system, materials, surface finish, fuel and so on), and SAE oil viscosity grades used. Historically, the reduction on fuel consumption is greatest when test bench and dynamometer test are performed compared with the results given by "on road" tests, these differences between methodologies can easily be explained by the additional losses that a given vehicle performing an equivalent driving cycle has to overcome (e.g. aerodynamic, rolling resistance and so on). On the other hand a vehicle performing the same driving cycle on a bench test dynamometer which has not to carry these losses will achieve the cycle profile requiring less power and thus the effect of LVO will be more noticeable.

The target of the study reported in this paper was to explore the potential of using a commercial LVO 5W20 SAE grade oil on a light duty diesel engine's friction and fuel consumption. As a reference baseline, a 5W30 SAE grade oil with the same additive

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package as the 5W20 was used. For the fired stationary test a 15W40 SAE grade commercial oil with a similar additive package was used as well.

2. Experimental setup

A high pressure direct injection, 4 cylinder, 1.6 l, turbo diesel engine, which meets Euro 5 regulations for light duty vehicles was employed. The engine specifications and the lubricants main characteristics are shown in Tables 1 and 2.

The engine was coupled with a Schenck-Pegasus dynamometer controlling online engine torque and speed. The control software used was a CMT “in-house” development named SAMARUC, able to program the driving condition of the vehicle. By means of this software the New European Driving Cycle (NEDC) was programmed as a time sequence for gears and vehicle speed taking into account the vehicle features and current driving skills. In order to register engine's parameters, Engine Control Unit (ECU) was totally opened and the engine setting maps could be calibrated with the ETAS INCA Software. The engine test bed was equipped with a series of temperature, pressure and air mass flow sensors in order to control the engine precisely. Fuel consumption was measured by means of a fuel gravimetric system, the AVL 733S Dynamic fuel meter. It consists of a measuring vessel filled with fuel suspended on a balance system. Fuel consumption values were then obtained by calculating the vessel's time related weight loss. As the response time of this system was too long for the dynamic study, a calibration of the fuel consumption signal provided by the ECU was performed in steady state. This ECU signal was used as a secondary fuel consumption measurement.

In this engine setup an external circuit to control coolant temperatures was set. However, the set up had no external circuit to control oil temperatures. Oil temperatures in this case were controlled varying the coolant flux in the engine intercooler, having reasonable results for the most of the test performed with the setup. Further discussions over the effectiveness of this setup and its incidence on every test will take place in the results section of this paper.

Table 1
Engine main characteristics.

Engine characteristics	Values
Displacement	1560cc
Cylinders	4 in line
Valves	2 Valves per cylinder
Max power	82 kW at 3600 rpm
Max torque	280 Nm at 1750 rpm
Turbo	Variable geometry
Emissions control	EGR, particle trap

Table 2
Lubricants main characteristics.

Oil properties	Oil A	Oil B	Oil C
SAE Viscosity grade	5W30	5W20	15W40
Base oil	API G-III	API G-III	API G-I
CCS viscosity (cP)	5120@ −30 °C	4519@ −30 °C	4878@ −20 °C
Kinematic viscosity at 40 °C (cSt)	53	45	107
Kinematic viscosity at 100 °C (cSt)	9.7	9.0	14.6
HTHS al 150 °C (cP)	2.9	2.8	3.7

3. Friction and fuel consumption test procedures

As it was mentioned before, the goal of this study is to assess the effect of lubricant viscosity on fuel consumption in light duty vehicle engines. To do so, an initial motored test focused on determining the real potential of the LVO to reduce the engine friction when the engine works on different engine speed was conducted. This test intended to measure the torque differences required by the dynamometer to reach several engine speed, being this a clear indicator of possible changes in mechanical losses. Then a screening over the engine's functional map was made by means of a stationary fired test. The purpose of this second test is to report the engine operating points where potential fuel consumption reduction due to LVO use are more noticeable. In this stationary fired test, BSFC obtained for each point with every oil is used as a comparison parameter. Finally, a transient cycle test was performed in order to address the effect of LVO when the engine works under real driving conditions. In this final test, the comparison was made taking into account the overall fuel mass consumed. These three methods are described largely in the following paragraphs.

3.1. Stationary motored test

This procedure consists in measure the required torque used by the dynamometer to motor the engine at certain speed. One objection to this method is the fact that in the absence of combustion the entirely variables which affect the engine's performance are misplaced (i.e. temperature profiles, air in cylinder pressure and parts strain). To get a more accurate approximation to the engine's operating conditions, motored tests should be performed after the engine has been working under fired conditions and controlling coolant and oil temperatures [12].

Although it does not simulate the engine's working conditions due to its unfired nature it has been widely used as an indicator of the engine frictional behaviour. For this test in particular, torque measures were taken for seven engine speed ranging from 1000 rpm to 4000 rpm, every 500 rpm.

3.2. Stationary fired test

The test under stationary fired condition took place in order to address the relative impact and possible fuel consumption benefit of LVO in specific stationary points of the engine's map. The stationary test offers a significant control level over the engine's variables (i.e. temperatures, engine's speed, among others), making easier to address the effect of any particular change of these variables in engine's performance. A 12 point screening on the engine's working map was planned to identify the working zones with more potential for fuel consumption reduction. The method employed consisted in compare the final torque output for each point at “iso-consumption” conditions for the three levels of viscosity given by the different oils and having oil A as the baseline. Each single point measurement has involved a three time repetition, every one of them being the average of engine's fuel consumption values on a 30 s period. To complete the test under “iso-consumption” conditions an initial round of measurements was made with oil A and using as inputs for each points the values given in Fig. 1 and Table 3.

Output parameters such as fuel flow rate, EGR%, GVT%, manifold inlet air pressure, and SOI were registered for each of the 12 points. After flushing oil A and replacing it with the candidate oil (oil B or C), the 12 points were measured again fixing this time, engine speed and fuel flow rate measured with oil A as inputs. Values of EGR%, GVT%, manifold air pressure and SOI were controlled to assure similar combustion conditions.