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Effect of commercial diesel fuel and hydrotreated vegetable oil blend on automobile performance

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Abstract. The new fuel 'Pro Diesel' that contains hydrotreated vegetable oil (HVO) was recently introduced in Baltic market. It raised some interest on performance of the new fuel among fleet and individual consumers. The authors evaluated and compared performance of modern M1 class automobile, using regular fossil diesel fuel and Pro Diesel fuel.
Torque, power and fuel consumption of the vehicle have been evaluated on chassis dynamometer, in steady state and driving cycle mode.
Depending on test conditions, engine power and torque was increased up to 2%, and fuel consumption reduced up to 3.9%, when diesel fuel/ HVO blend was used.

Key words: Pro Diesel fuel, HVO, NexBTL, compression ignition engine, fuel consumption, power, torque.

INTRODUCTION

Since April 2016, the largest Neste Oil fuel retail stations in Latvia started to offer new brand of fuel – 'Neste Pro Diesel', which contain hydrotreated vegetable oil (HVO) approximately 15% by volume.

HVO can be produced from many kinds of fats. Their production need not be based only on processing of raw vegetable oils, but other kinds of waste triglycerides-rich materials (used cooking oil, animal fats) can be used as well (Huber et al., 2007).

Renewable feedstocks such as vegetable oils may be processed by variations of conventional petroleum refining, including hydrotreatment. These refining methods produce saturated paraffinic hydrocarbon molecules with extremely low aromatic levels and a very narrow distillation range, and properly processed, they can provide the required cold flow properties (Worldwide Fuel Charter, 2013).

The different physical and chemical properties of the fuel affects the combustion processes in the engine. As a result, the power and torque performance of the vehicle as well as fuel consumption and exhaust emission composition is changing.

The aim of this study was evaluate and compare performance and fuel consumption of modern M1 class automobile, using regular fossil diesel fuel and Pro Diesel fuel.

There are number of studies done on performance and fuel consumption characteristics of HVO and its blends with fossil diesel fuel in diesel engines during the last years.

Extensive studies have been done in Finland (Nylund et al., 2011) within the frame of OPTIBIO project, where the HVO fuel was tested in 300 urban buses. The test fuels were a 30% HVO blend and 100% HVO. In this study the fuel consumption measurements was carried out with 11 different buses. It was concluded that maximum increase in volumetric fuel consumption was 1.4% for the 30% HVO blend and 5.2% for 100%.

Within the same project the effects of injection timing on exhaust emissions and fuel consumption was studied at Aalto University with an engine equipped with an adjustable common-rail fuel injection system and running on 100% HVO. There was concluded that choosing a calibration that delivers NOx at the same level as with regular diesel fuel results in a 4% reduction in energy consumption and a reduction of some 40% in filter smoke number. If a slight increase (4%) in NOx can be allowed, energy consumption can be reduced as much as 6% (Nylund et al., 2011).

The difference in power and fuel consumption of tractor Claas Ares running with pure HVO fuel and fossil diesel have been studied in Latvian University of Agriculture. In these studies it was found that the engine effective power and torque using HVO fuel decreases relatively to fossil diesel fuel. The average PTO (power take-off) power and torque reduction was about 5.0%. It can be explained by the 5.5% difference in the volume-based lowest heating values of both fuels. The average hourly fuel consumption in PTO revolutions range from 300 to 625 min^{-1} using HVO was by about 1% lower comparing to diesel fuel, but due to the lower developed engine power the increase of the specific fuel consumption was in average by 4.1% higher (Sondors et al., 2014).

Aatola et al. (2008) have studied NO_x – particulate emission trade-off and NO_x – fuel consumption trade-off using different fuel injection timings in a turbocharged charge air cooled common rail heavy duty diesel engine with sulfur free diesel fuel, neat HVO, and a 30% HVO + 70% diesel fuel blend. Results showed that the use of 100% HVO decreases the specific fuel consumption (SFC)of the engine at all engine speeds and loads at each measured injection timing when comparing with EN 590 and EN 590-30 diesel fuels. With EN 590-30 diesel fuel, the decrease of SFC compared to EN 590 diesel fuel is, of course, not that clear.

Kim et al. (2014) carried out the study of engine performance to compare iso-HVO (isomerized-hydrotreated vegetable oil) with BD (Biodiesel). The test samples were prepared 16 kinds of fuels, which are fossil diesel and 2%, 10%, 20%, 30%, 50% of BD, HVO, and iso-HVO blended diesel, respectively. The engine performances and emission were tested on engine dynamometer and chassis dynamometer with 1.5 l diesel engine and passenger car, for evaluating maximum power, fuel consumption, and emission, especially PM (Particulate Matter) and NO_x. Iso-HVO has much better engine performance than BD and slightly better than HVO, but slightly worse than fossil diesel. In this study HVO blended diesel show decreases in the power, meaning that the more HVO or iso-HVO blended, the more power decreased. Decrease of maximum power depends on the driving conditions, and normally, fuel injection control of the engine in the maximum power mode is conducted by fuel volume. Kim et al. (2014) also reports, that HVO and iso-HVO show slightly decrease of fuel consumption while blending ratios of them increase.

Pellegrini et al. (2015) have studied the potential of HVO as blending component of diesel fuel to be used in advanced combustion systems at different compression ratios and at high EGR rates. The experiments were carried out in a single cylinder research engine at three steady state operating conditions and at three compression ratios (CR) by changing the piston. The two of test fuels comprised 15 and 30% of HVO. They found that as the engine compression is reduced, the use of HVO fuel blends allows for more efficient combustion timing and so reduces the fuel consumption.

Also Pexa et al. (2015) carried out the study of 100% rapeseed methyl ester and 100% hydrogenated oil impact on the operational characteristics of a turbocharged internal combustion engine of the tractor Zetor Foretrra 8641 using a dynamometer to the PTO. It was observed that during the operation with HVO fuel, the engine maximum torque reduces by approx. 0.9% and the maximum performance reduces by approx. 6%. The specific fuel consumption of the HVO fuel reduces in comparison to the RME fuel almost in the whole speed range.

Most of the researchers, who tested blends of paraffinic fuel (HVO, gas to liquid (GTL)) with diesel fuel, using compression ignition (CI) engines with CR above 17:1, reported decrease of engine maximal torque and power, comparing to diesel fuel (Uchida et al., 2008; Wang et al., 2009; Kim et al., 2014). It was explained by lower volumetric heating value of paraffinic fuel. Kitano et al. (2005) tested GTL fuel, using engine with CR 16:1 and reported no change in engine power and torque, comparing GTL to diesel fuel.

MATERIALS AND METHODS

Two fuels were used in this study – Neste Pro Diesel (ProD), which contained hydrogenated vegetable oil, and regular fossil fuel Neste Futura. General properties of test fuels according the certificates of conformity are presented in Table 1.

Table 1. Basic parameters of tested fuels

Parameter	Fossil Diesel Fuel	HVO Blended Diesel Fuel
Fuel designation	Neste Futura	Neste Pro Diesel
Density at 15 °C, kg m^{-3}	824.4	822.2
Cetane number	51.1	55
Viscosity at 40 °C, mm^2 s^{-1}	1.937	2.537
Flash point, °C	62	67.5
Content of HVO, % vol	0	9.15

The four-wheel drive car Mazda CX-5 of 2015 equipped with a 2.2-liter Euro 6 engine with compression ratio 14.0:1 was used in this study. The effective power of the vehicle was 129 kW and it was equipped with Common-rail fuel system. The torque was transmitted to the wheels through a 6-speed automatic transmission. The rear axle drive of the test car was mechanically unlocked for the tests on chassis dynamometer.

The study was performed in Scientific Laboratory of Alternative Fuels of Latvia University of Agriculture on chassis dynamometer Mustang MD-1750. For measurement of power and torque on driving axle and fuel consumption the following tests were performed: power test, idle running test, constant speed tests (50 km h^{-1}, 90 km h^{-1} and 110 km h^{-1}), driving cycle IM-240 and especially worked driving cycle 'Jelgava'. The driving cycle IM-240 represents the combined driving cycle. The cycle simulates both the urban driving conditions where the maximum speed doesn't exceed 50 km h^{-1} and driving in non-urban area. The total duration of cycle is 240 seconds and the covered distance is 3.10 km. The driving cycle 'Jelgava' is localy eleborated city driving cycle that simulates as close as possible the real driving in one of the cities of Latvia – Jelgava. The total duration of this cycle is 360 seconds and covered distance is 2.36 km. Technical characteristic of driving cycle 'Jelgava' and peculiarities of elaboration are described in publication (Dukulis & Pirs, 2009).

Constant speed tests were performed for 60 seconds with the reading step of 1 second. Three repetitions were made in each testing mode. The gear shifter was set in automatic mode.

Load conditions were simulated in the laboratory on the eddy current roll type chassis dynamometer Mustang MD1750.

Fuel consumption was measured using the high precision and accuracy fuel consumption measurement system AVL KMA Mobile. System measuring range is 0.35–150 L h^{-1} and measuring error – 0.1%.

The layout of test equipment are shown in Fig. 1.

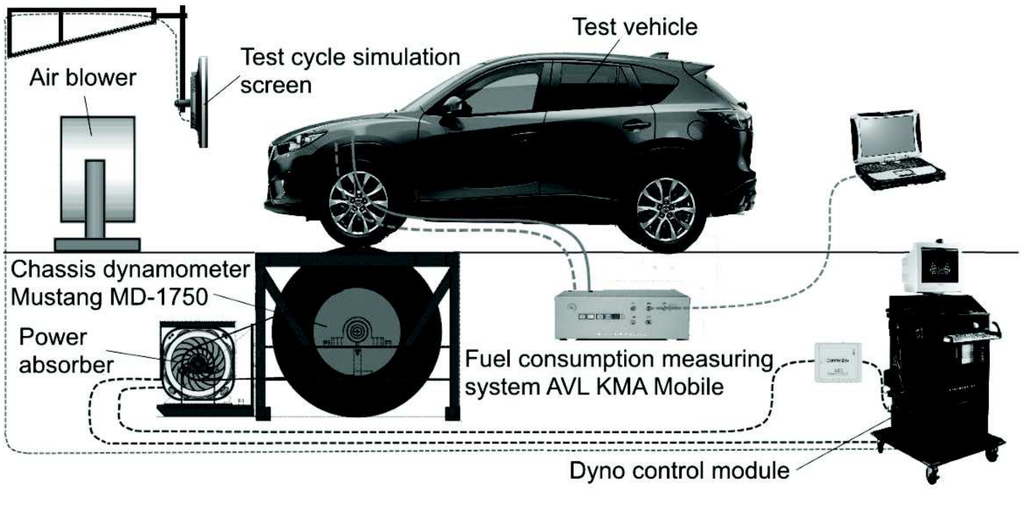

Figure 1. Test object and measuring equipment.

RESULTS AND DISCUSSION

The results of vehicle power and torque tests with both test fuels are presented in Fig. 2. At medium and high engine speeds the vehicle power and torque values are very similar. Significant power and torque increase was observed at low engine speeds (up to ~ 2,200 min^{-1}), during vehicle operation with Neste Prodiesel fuel.

The maximum power value of 106.8 ± 0.6 kW was reached during vehicle operation with ProDiesel fuel which is by 1.2% higher than in case of fossil diesel use. The maximum torque value also was higher for Pro Diesel fuel by 2%.

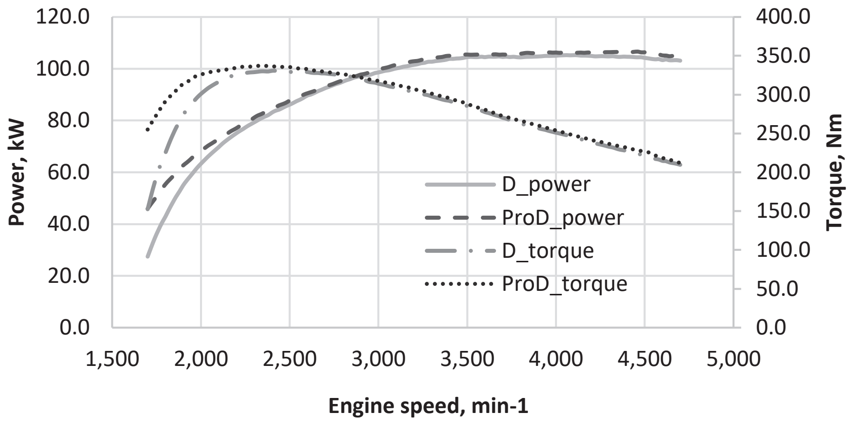

Figure 2. Vehicle power and torque curves.

The difference in power and torque values between test fuels within the whole speed range is shown in Fig. 3. The power and torque increase in vehicle operation with ProDiesel fuel at crankshaft speed 1,700 min^{-1} reach 67% compare to fossil fuel Futura.

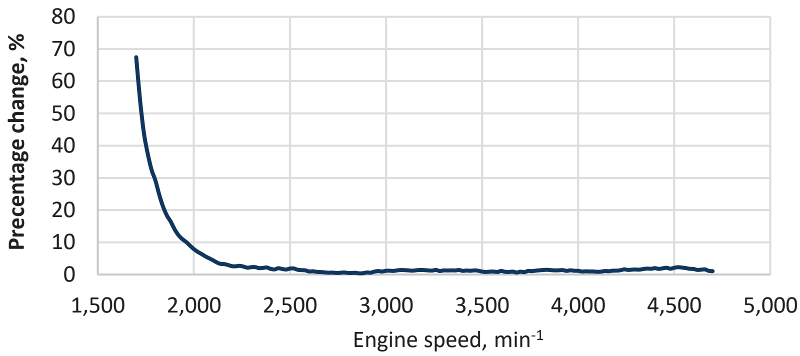

Figure 3. Vehicle power and torque percentage changes.

The difference in power and torque values can be attributed to to fuel properties, as well as a suitability of specific engine design (low compression ratio) and engine management system setup for fossil or ProDiesel fuel. Comparing to work of other researchers, commercial fuel blend was used and engine compression ratio was lower. In order to find explanation of above mentioned difference in power and torque the further studies on impact of HVO containing fuel properties on combustion process are necessary.

The difference in fuel consumption at vehicle idle operation between tested fuels were not observed. Both in case of Neste Pro Diesel and Neste Futura fuel the idling fuel consumption was 0.50 ± 0.02 L h^{-1}. The vehicle operation with HVO containing fuel in steady speed mode shows the overall trend of fuel consumption decrease (see Fig. 4.). The fuel consumption decrease with ProDiesel fuel at steady speed modes of 50, 90 and 110 km h^{-1} was 1.5%, 0.7% and 3.7% respectively.

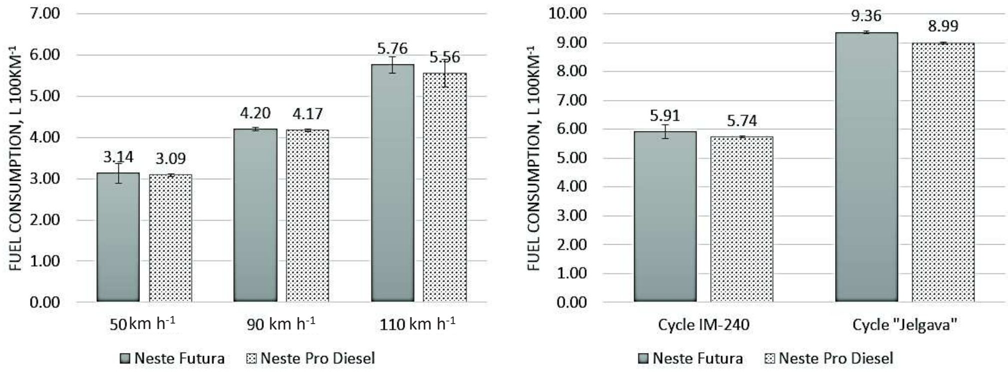

Figure 4. Fuel consumption in steady speed and driving cycle modes.

More evident fuel consumption changes was observed at variable load drive conditions or driving cycles. The vehicle operation with fuel containing HVO at driving cycle IM-240 showed the reduction in fuel consumption by 0.17 L 100 km^{-1} or 2.9% comparing to operation with fossil diesel. Whereas, the fuel consumption decrease at driving cycle 'Jelgava', which represents the movement of the vehicle in an intensive city traffic was 0.37 L 100 km^{-1} or 3.9%.

The observed decrease in fuel consumption partially could be explained by reduced engine compression ratio according to the studies performed by Pellegrini et al. (2015).

CONCLUSIONS

The results of the study show that test vehicle operating on fuel with admixture of hydrogenated vegetable oil at 9.15% by volume develops about 1.2% higher maximum power and 2% higher peak torque. However, the most significant difference between test fuels appear especially at low engine speed. The methodology and measuring equipment used in this study do not allow reveal the reason for that parameter changes. The partial impact on the result would leave both the different fuel physically - chemical properties as well as specific characteristic of vehicle engine and engine management system program set up.

The data of fuel consumption analysis showed that operation on fuel with admixture of hydrogenated vegetable oil at 9.15% by volume reduces the vehicle fuel consumption both in steady and transient driving modes. In steady driving modes at 50, 90 and 110 km h^{-1} the fuel consumption decreases by 1.5%, 0.7% and 3.7%. The vehicle operation with ProDiesel fuel in driving cycles IM-240 and 'Jelgava' shows 2.9% and 3.9% reduction of fuel consumption respectively compare to fossil diesel.

For reasonable explanation of obtained results the relation of particularities of engine design, fuel system and engine control system with the fuel physically-chemical characteristics of ProDiesel fuel must be analyzed in a further studies.

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