EMISSIONS AND PERFORMANCE OF A PASSENGER CAR SIZE DIESEL ENGINE FUELLED WITH HVO DIESEL FUEL MIXTURES

I. Bortel[1], J. Vávra[1], M. Takáts[1]

1. CTU in Prague, Faculty of Mechanical Engineering, Technická 4, Praha 6

Introduction

Compression ignition (CI) engines are used in a wide range of applications including passenger car engines. The main advantage of CI engines in comparison with spark ignition ones (SI) is a higher overall fuel conversion efficiency [1] and related reduction of emissions of CO_2 from passenger cars.

Renewable biofuels can help to reduce Green-House Gases (GHG) including CO_2 with benefits in Particulate Matter (PM) emissions [2], [3] and particle number (PN) [4].

Nowadays, fatty acid methyl esters (FAME), ordinarily known as biodiesel, produced from vegetable oils, waste cooking oils, and animal fats seems to be the biofuel of choice for fossil diesel fuel replacement [4]. However, FAME fuel usage brings in inconveniences like oil aging [5], limited storage time of fuel [6] and cold properties of FAME [7].

Hydrotreated vegetable oil (HVO) is made by a refinery-based process that converts vegetable oils and animal fat into paraffinic [8], [9]. HVO fuel does not have the detrimental effects of ester-type biodiesel fuels, such as problems mentioned above, increased NO_x emission and deposit formation. HVO is a straight chain of paraffinic hydrocarbons that are free of aromatics, oxygen and sulphur and has a high cetane number [8].

Typical density of HVO is between 770 to 790 kg/m^3 [7] and consequently the volumetric heating value of HVO is 5% lower than fossil diesel fuel [9]. The article [9] states, that injection volume quantity of HVO is about 5 % higher than injection volume quantity of standard diesel fuel due the lower bulk modulus of HVO in comparison with standard diesel fuel. Other explanations are mentioned in [7] and [9]. Therefore it looks, that energy quantity in fuel per cycle is not significantly affected by using HVO in comparison with standard diesel fuel [7], [9].

High cetane number of HVO accelerates the start of combustion in low and medium loads, but is of less influence at high loads. Furthermore, the high cetane number particularly improves cold startability, reduces noise and emissions [7]. Engine's energy efficiency can be slightly improved with HVO [7], [11].

Using pure HVO or blends of HVO and standard diesel fuel reduces emissions of hydrocarbons (HC), carbon monoxide (CO) [7], [8], [14] and particle matter (PM) emissions [7], [12], [13], [9], especially at low temperatures [7]. Some authors observe small increase in PM with HVO blends, but only in several cases, not in general [4].

Particle number (PN) emissions showed reductions with HVO fuel [4], [13].

Influence of HVO on NO_x emission seems to be ambiguous [5]. In several articles the reduction of NO_x is stated [7], [8], while somewhere the negligible effect [4], [12], [14], or growth of NO_x emissions is mentioned [13].

HVO content in regular diesel fuel does not cause clogging or premature deactivation of aftertreatment devices, like DPFs, DOCs or SCRs [7]. Authors in [15] state, that regeneration ability of DPF is improved by usage of HVO.

corresponding author: Ivan Bortel, ivan.bortel@fs.cvut.cz

This study extends the available results of HVO blends tests on CI engines of passenger car size instead of most commonly observed heavy duty engines. The main contributions are a wide range of tested modes of engine, based on WHSC (World Harmonized Stationary Cycle) test [16], [17], usage of contemporary common rail injection system and measurement of PN and PM emissions.

Tested fuels

Three fuels were tested, regular diesel fuel without biofuel (RD), mixture regular diesel fuel and 30 % HVO (HVO30) and pure HVO (HVO100).

Test Engine

The experiments were conducted on a single cylinder research engine (AVL 5402) with common rail diesel injection, which parameters, bore 85 mm and stroke 90 mm, correspond to contemporary engines of passenger cars. Engine is supercharged via external compressor with an inlet air conditioning unit. Real world exhaust back pressure, caused by aftertreatment devices and turbine, is emulated by the throttle valve in the exhaust manifold. Fuel injection strategy with pilot and main injections was used. The equal settings of ECU was used for all tested fuels. Exhaust gas recirculation (EGR) was not used for any mode.

Measurement equipment

Diesel fuel consumption was measured with the AVL733 dynamic fuel balance. All emissions were measured in the raw exhaust gases and all specific emissions were evaluated from the raw exhaust gas. Particle number (PN) was measured with the AVL 489 Particle Counter. Gravimetric particulate matter (PM) measurements were obtained using an AVL Smart Sampler 472.

All gaseous emissions were measured by AVL AMA i60. Nitrogen oxides were measured using chemical luminescence detector method (CLA), total hydrocarbons and methane emissions via flame ionization detector (FID), and carbon monoxide and carbon dioxide via non-dispersive infrared (NDIR) measurement technique. Content of oxygen was measured by a paramagnetic detector (PMD).

Methodology

The tested modes of engine were defined by WHSC test. This test includes representative modes of engine with different speeds and loads. The WHSC test procedure was slightly modified: The stabilization for each tested modes was added and all assessed parameters were measured after this stabilizations. The test includes 13 modes and each mode has its own weight factor. Assessed quantities are weighting average of all 13 modes of test. All specific quantities are related to engine indicated power.

Results and discussion - energetic parameters

Averaged indicated power P_i [kW] per cycle is increased proportionally to the growth of the concentration of HVO in regular diesel fuel. Growth of 1.41 % for HVO30 is negligible, but Increase by 4.53 % for HVO100 can be considered to be provable. Impact to ISHC seems to be negligible. Similar effect was observed in [7], [11].

Results and discussion - gaseous emissions

Drop of indicated specific emission of CO_2 by 3.56 % was observed, when the diesel fuel was fully replaced by HVO. HVO has higher hydrogen/carbon ratio (H/C) [9], [11], [12], [18], what helps mentioned effect together with growth of P_i mentioned above.
Significant drop in emission of CO**Chyba! Nenalezen zdroj odkazů.** and in hydrocarbon (HC) emission is observed, while HVO concentration in regular diesel fuel is increased (Figure 1). It is caused by several different properties of HVO fuel in comparison with regular diesel fuel. The lower distillation range improve the fuel evaporation and mixing with surrounding air, the higher cetane number provides high reactivity at low combustion temperature and low loads [9], [11].

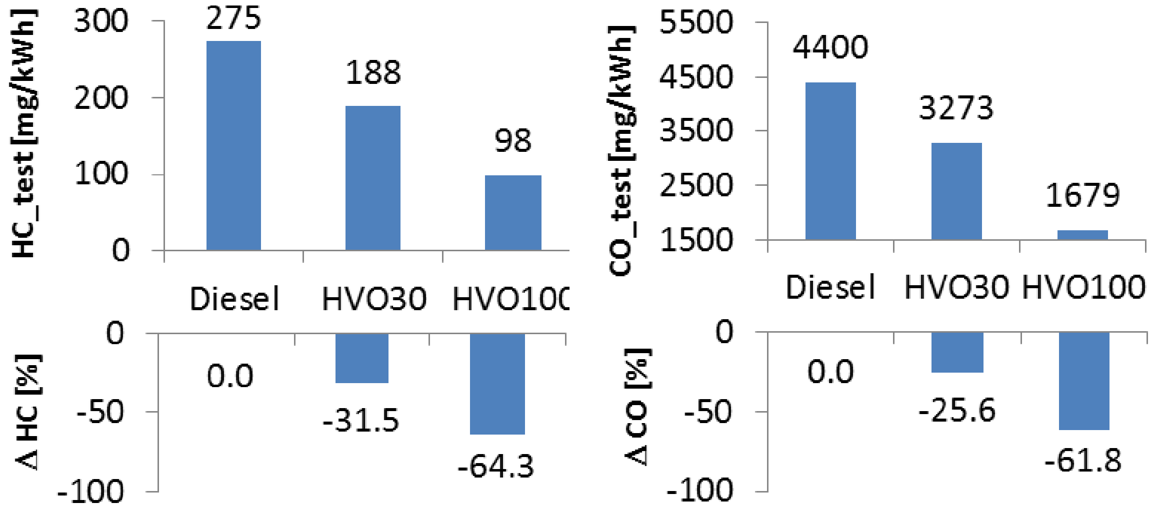

Figure 1 Indicated specific hydrocarbon (HC) and carbon monoxide (CO) emission – average per test

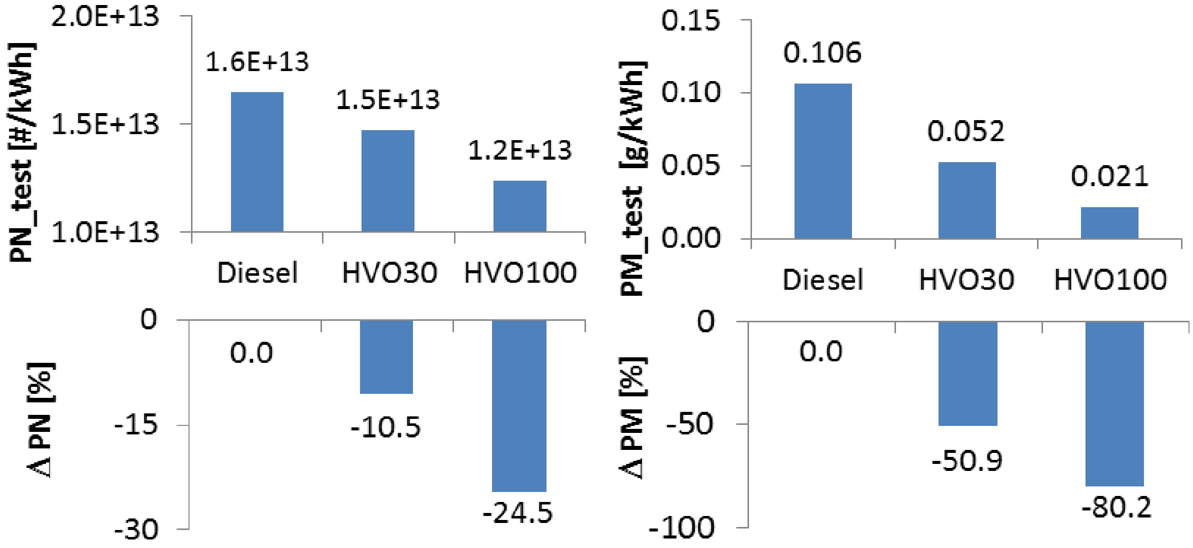

Figure 2 Indicated specific particle number (PN) and particulate matter (PM) emission– average per test

Higher HVO content in regular diesel fuel causes slight decrease of NO_x emission, 3.6 % for HVO30 and 4.2 % for HVO100. This effect is also observed in [7], [8]**Chyba! Nenalezen zdroj odkazů.**. Slight or ambiguous influence of HVO to NO_x emissions seems to be positive in comparison with growth of NO_x emission with FAME blends [4]. The ambiguous influence to NO_x emission can depend on combined effects between ignition delay and fuel injection quantity [11].

Results for particle number (PN) and particulate matter (PM) are shown in Figure 2. The significant drop in PM emission and in PN emission with the pure HVO fuel (HVO100) are achieved. Results achieved with 30% HVO content in regular diesel fuel shows, that significant reduction of PM with lower concentrations of HVO is attainable. Effect of HVO30 to PN and PM emission is more than proportional to HVO concentration in comparison with results achieved with HVO100.

Drops in PN, PM, is positively affected by the absent of aromatic hydrocarbons in HVO, lower distillation range and higher cetane number [9], [11] in comparison with regular diesel fuel.

Conclusions

It seems, that benefits of usage HVO in PN, PM, CO and HC emissions and marginal effect to NO_x open new possibilities for optimization of ECU strategy for PM-NO_x trade-off. Nevertheless, presented positive results are attained without any optimization for HVO30 of HVO100 fuel. Furthermore, analysis of emissions of individual modes shows, that HVO content in regular diesel fuel improves CO and HC emissions significantly and improves NO_x at idle and light load modes. Therefore HVO has potential to improve emission in urban traffic, where these modes are typical and exhaust temperature is below of optimum for aftertreatment systems. It is expected, that HVO content in regular diesel fuel reduce unburned fractions at low combustion temperature [11].

Acknowledgement

This research has been realized using the support of The Ministry of Education, Youth and Sports program NPU I (LO), project # LO1311 Development of Vehicle Centre of Sustainable Mobility. This support is gratefully acknowledged.

The study has been performed within the framework of the project of The Ministry of Agriculture of the Czech Republic NAZV QJ1510385.

Authors would like to thank to colleague Ondřej Gotfrýd for support of ECU parametrization.

References

[1] Heywood, J. B., Internal combustion engine fundamentals, New York: McGraw- Hill; 1998, ISBN 0-07-028637
[2] Malhotra, R.K., and Sarin, R., “Bio-diesel for Energy Security, Environment Protection and Employment Generation,” SAE Technical Paper 2004-28-030, 2004.
[3] McCormick, R.L., Williams, A., Ireland, J.,Brimhall, M. and Hayes, R.R., Effects of biodiesel blends on vehicle emissions, Int. J. Eng. Res. 2006: 2:249-61, 2006
[4] Karavalakis, G., Jiang, Y., Yang, J., Durbin, T. et al., Emissions and Fuel Economy Evaluation from Two Current Technology Heavy-Duty Trucks Operated on HVO and FAME Blends, SAE Int. J. Fuels Lubr. 9(1), 2016, doi:10.4271/2016-01-0876
[5] Singer A., et al., Aging studies of biodiesel and HVO and their testing as neat fuel and blends for exhaust emissions in heavy-duty engines and passenger cars, FUEL, vol. 153, pp. 595–603, 2015

[6] Ohshio, N., Saito, K., Kobayashi, S., and Tanaka, S., Storage Stability of FAME Blended Diesel Fuels," SAE Technical Paper 2008-01-2505, 2008, doi: 10.4271/2008-01-2505.

[7] Hartikka, T., Kuronen, M. and Kiiski, U., Technical Performance of HVO (Hydrotreated Vegetable Oil) in Diesel Engines, SAE Technical Paper 2012-01-1585, 2012, doi:10.4271/2012-01-1585

[8] Aatola, H., Larmi, M., Sarjovaara, T., and Mikkonen, S., Hydrotreated Vegetable Oil as fuel for heavy duty diesel engines, SAE 2008-01-2500, 2008

[9] Sugiyama, K., Goto, I., Kitano K., and Mogi, K., Effects of Hydrotreated Vegetable Oil (HVO) as Renewable Diesel Fuel on Combustion and Exhaust Emissions in Diesel Engine, SAE Technical Paper 2011-01-1954, 2011

[10] Crepeau, G., Gaillard, P., van der Merwe, D., and Schaberg, P., Engine Impacts and Opportunities of Various Fuels, Including GTL and FAME: Toward Specific Engine Calibration?, SAE Technical Paper 2009-01-1787, 2009, doi:10.4271/2009-01-1787.

[11] Jaroonjitsathian, S., Saisirirat, P., Sivara, K., Tongroon, M. et al., Effects of GTL and HVO Blended Fuels on Combustion and Exhaust Emissions of a Common-Rail DI Diesel Technology, SAE Technical Paper 2014-01-2763, 2014, doi:10.4271/2014-01-2763

[12] F. Millo et al., Experimental Investigation on the Effects on Performance and Emissions of an Automotive Euro 5 Diesel Engine Fuelled with B30 from RME and HVO, SAE Technical Paper 2013-01-1679, 2013, doi:10.4271/2013-01-1679

[13] Nylund, N., Hulkkonen, T., Tilli, A., Mikkonen, S., Saikkonen, P., and Amberla, A., Emission performance of paraffinic HVO diesel fuel in heavy duty vehicles, SAE Technical Paper 2011-01-1966, 2011, doi:10.4271/2011-01-1966

[14] Pellegrini, L., Beatrice, C., and R Blasio, G., Investigation of the Effect of Compression Ratio on the Combustion Behavior and Emission Performance of HVO Blended Diesel Fuels in a Single-Cylinder Light-Duty Diesel Engine, SAE Technical Paper 2015-01-0898, 2015, doi:10.4271/2015-01-0898

[15] Rodríguez-Fernandez, J., Lapuerta, M., Sanchez-Valdepenas, J., Regeneration of diesel particulate filters : Effect of renewable fuels, Renewable Energy journal vol. 104, pp. 30–39, 2017

[16] http://new.eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:42013X0624(01)&from=EN

[17] https://www.dieselnet.com/standards/cycles/whsc.php

[18] Bhardwaj, O., Lüers, B., Holderbaum, B., Koerfer, T. et al., Utilization of HVO Fuel Properties in a High Efficiency Combustion System: Part 2: Relationship of Soot Characteristics with its Oxidation Behavior in DPF, SAE Int. J. Fuels Lubr. 7(3), 2014, doi:10.4271/2014-01-2846