COST-STSM-CM1404-32067 SCIENTIFIC REPORT

STSM Topic: Regular (SMARTCATS)

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Background/ Purpose of the STSM

The advanced and developing economies are strongly dependent on fossil fuels for transportation. It is estimated that within the EU countries around 90% of the CO_2 emissions between 1990 and 2010 are attributed to the transportation sector. For this reason the European Union and other developing countries have established specific action plans for the promotion of biofuels in their markets, such as the Directive 2003/30/EC which suggested that all Member States should blend biofuels in conventional fuels at a 2% ratio in 2005, which will gradually rise up to 5.75% in 2010. In 2007 the EU Commission put forth the ambitious “20/20” energy-climate package for reducing the GHG emissions by 20%, which included a 10% share of biofuels in the transportation sector by 2020. First generation biodiesel known as FAME (free fatty acid methyl ester) faces many limitations in its use to diesel car engines, second generation biofuel technologies have been developed to overcome the limitations of first generation biofuels production.

In general, first generation biofuels (FAME) have the potential to reduce the greenhouse emissions and for this reason there are many studies on the literature that examine the reduction of emissions by using different types of FAME biofuels. However, most of the studies that compare the emissions of biofuels to the emissions of fossil fuel content only change the fuel and measure the emissions. While the engine nominal settings are optimal for conventional diesel combustion, they are not anticipated to be optimal for biodiesel combustion due primarily to its different physical and chemical properties. HVO is a second generation biodiesel produced via two step hydrotreating of vegetable and used oils, this fuel is a paraffinic fuel with lighter hydrocarbons, higher heating value, higher cetane number, no aromatic content, no oxygen content and lower density compared to market diesel. As a result, adjustments in operating parameters of the engine with HVO fuel, such as exhaust gas recirculation (EGR) system, main injection timing (IT), injection pressure (IP) and pilot injection timing can potentially further improve the emissions and combustion characteristics of the engine. Table 1 presents the properties of renewable HVO fuel compared with a typical market diesel of a fuel station of Greece.

Table 1 Properties of renewable HVO fuel compared with a typical market diesel

Properties	Unit	Market Diesel	HVO
FAME content	% v/v	7	0
Density at 60°C	Kg/m3	832.4	778.7
Kinematic viscosity	Mm2/s	3.236	2.82
Flash point	°C	59	83
Cloud point	°C	-5	-22.2
Sulfur content	Ppwt	9.1	<5.0
Cetane number	-	56.5	76.3
Cetane index	-	54.7	
Ash content	%m/m	0.002	<0.001
Water content	Mg/kg	160	20
Polyaromatic hydrocarbons	%m/m	2.2	0
CFPP	°C	-5	-21
Heating value	MJ/kg	43	44
Oxidation stability	hr	>6	>22
Distillation	°C	191-357	189-301
A/F_s	-	14.2	15.2
Oxygen content	% wt	0.77	0
C:H ratio	-	7.26	5.49
Hydrogen content	% wt	12	15.4
Carbon content	% wt	87.23	84.6

The aim of the visit to University of Ljubljana was to evaluate the feasibility of using second generation renewable diesel fuel (HVO) to a diesel engine of a small passenger car by adjusting the operating parameters of the engine to gain full advantage of renewable fuel properties. Centre for Research & Technology Hellas (CERTH) has an extensive experience in catalytic hydroprocessing of bio based feedstocks for biofuels production. More specifically a technology for second generation high quality renewable diesel production via hydrotreated of vegetable oils (HVO) has been developed by CERTH. A second generation HVO fuel was tested in a diesel engine to examine the effect of different operating parameters of the engine.

Until now, the individually effect of EGR system as well as the injection timing (IT) have been examined in a direct injection diesel engine using HVO fuel, and compared with a commercial market diesel at default engine settings. The results have shown that the use of HVO fuel in combination with operating adjustments of the engine provides many benefits in a diesel engine, reducing all regulated emissions and improving combustion characteristics. However, both EGR and IT were studied individually. According to the findings, a combination of EGR and IT would further improve the emissions and combustion of the engine when it is running with HVO fuel, benefiting from the advantageous HVO properties. However the research of CERTH is limited only on renewable fuel production. University of Ljubljana has the expertise and the equipment to perform experiments on a diesel car engine and employing additional operating adjustments. As a result, a series of experiments was performed in order to evaluate the best engine operating adjustments with HVO fuel. The obtained results will give the opportunity to adjust a diesel engine when it is running with renewable diesel fuel, to take full advantage of HVO properties, which characterized as a better quality fuel (due to its paraffinic nature) compared to market diesel. The cooperation between the research institutions gave the opportunity to combine the available equipment, scientific staff and knowledge of both institutions to move the research one step forward.

Description of the work carried out during the STSM

Week 1 -2 (29th February- 13th March) Modification of the engine for testing HVO fuel

Two fuels were examined during the investigation, a commercial market diesel as a reference fuel and a second generation renewable biofuel producing via hydroprocessing of vegetable oil (HVO). The reference fuel was a standard low sulphur market diesel from a fuel station in Ljubljana. HVO (hydrotreated vegetable oil) was a paraffinic fuel produced via two step hydroprocessing from Neste oil Corporation in Finland. The HVO is fully paraffinic and thus it contains no aromatics, sulphur and oxygen.

The engine tests were conducted on a Euro 4 turbocharged diesel engine which is used in small passenger cars. The basis of the test set-up is 4-cylinder, 4-stroke, turbocharged, intercooled 1.6 liter PSA light-duty Diesel engine (model DV6A TED4), which was coupled with a Zöllner B-350AC eddy-current dynamometer controlled by Kristel, Seibt & Co control system KS ADAC. The basic characteristics of the engine are presented in Table 1.

Table 2 Peugeot engine from laboratory of Mechanic Engineers in Ljubljana Slovenia

Engine code	DV6ATED4 (9HX)
Particle filter	Without
Number of cylinders	4 (DOHC)
Bore x stroke (mm)	75 x 88,3
Cubic capacity	1560
Fuel	Diesel
Maximum power (kw)	66,2 @ 4000 rpm
Maximum torque (Nm)	215 @ 1750 rpm
Oil capacity wo/w filter	3,25 (3,75)
Compression ratio	1/18
Emission control standards	EURO 4
Catalytic converter	Yes
ECU type	EDC 16C34
CR pump type	CP1 H
Injection sequence	1-3-4-2
Combustion chamber depth (mm)	13,2
Combustion chamber diameter (mm)	41,7
Piston pin offset (mm)	0,4 ± 0,075
Conrod length (mm)	136,8 ± 0,025

A Kistler CAM UNIT Type 2613B shaft encoder provided an external trigger and an external clock at 0.1 deg CA for data acquisition and injection control system. In-cylinder pressure was measured with calibrated piezo-electric pressure transducer AVL GH12D in combination with charge amplifier AVL MICROIFEM, connected to 16 bit, 4 channel National Instruments data-acquisition system with maximum sampling frequency 1 MS/s/ch. Top dead center was determined by capacitive sensor COM Type 2653.

Data acquisition and injection control embedded system, in the Fig. 1 depicted as NI cRIO system, was based on National Instruments cRIO 9024 processing unit and 9114 chassis. Along with indication of pressure traces, it generated digital output signals to set start and duration of injectors energizing at Driven system, which can be set in PC graphic user interface. Driven system generated inlet metering valve signal (IMV signal) and injector energizing signal (IE signal) to control common rail pressure and fuel injection times. It was connected to the PC and energizing characteristic for the injectors along with other Driven parameters was set CalView software. The engine is shown in Fig. 2.

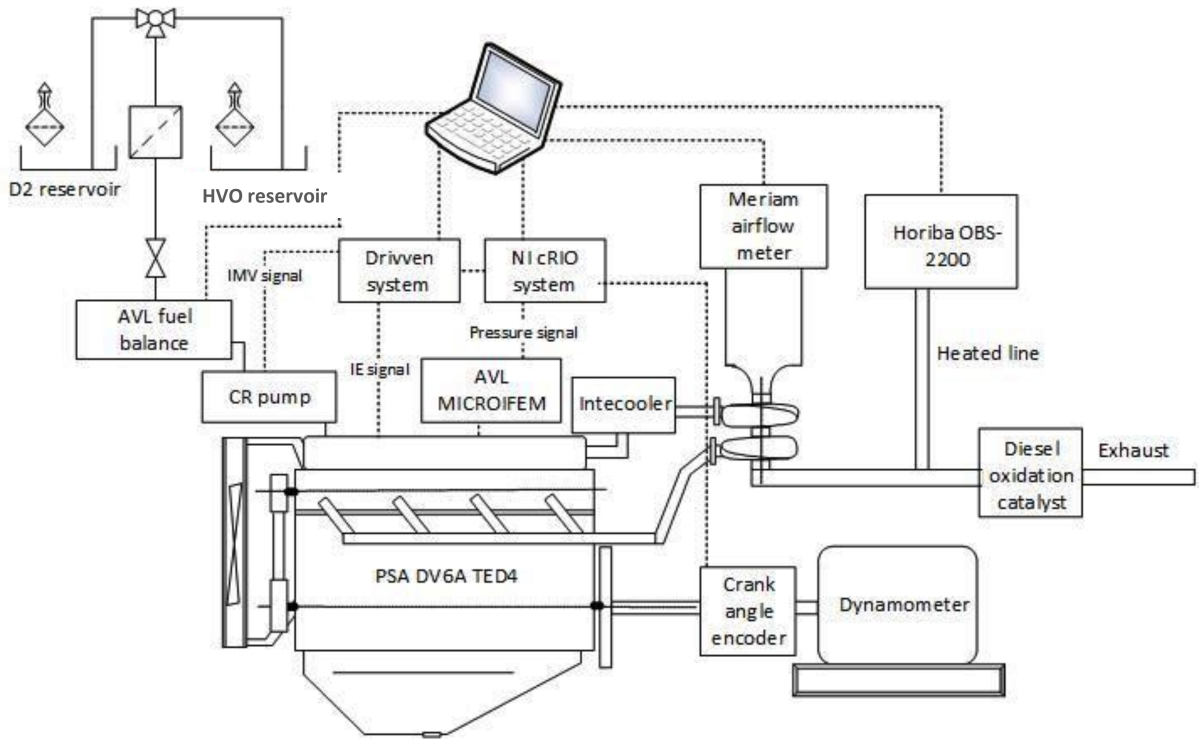

Figure 1 schematic diagram of the experimental setup

Figure 2 Peugeot engine from laboratory of Mechanic Engineers in Ljubljana Slovenia

The first two weeks of the STSM was dedicated to modify the car engine in order to be able to control the EGR valve position manually combined with the control of injection timing. A new intake manifold was modified and an oxygen sensor was added for oxygen measurement inside the intake system as it is depicted in Fig. 3. Furthermore a custom made two way system was created in order to be able to change the fuel during the experiments between market diesel (reference fuel) and HVO fuel (Fig. 4). Moreover, a custom made control system was built to control manually the EGR valve position as depicted in Fig. 5. During this period, I was introduced to the basics of the engine modifications and how to run the engine and all the requiring equipment for carrying out the experiments of the research.

Figure 3 Intake manifold - oxygen sensor

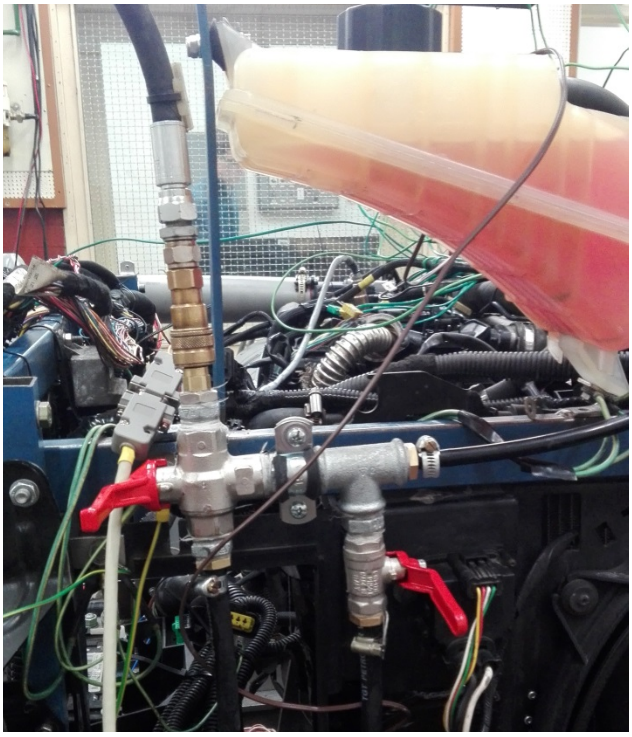

Figure 4 Two way feed system of the engine

Figure 5 EGR valve position controller

Week 3 (14th March- 20th March) Experiments - Measurements

The third week 14th March – 20th March we carried out all the requirement experiments with both fuels, market diesel as a reference case and HVO fuel as a second generation renewable biodiesel. The engine was initially tested with both fuels (market diesel and HVO) over 20 operating steady points as they are depicted in Fig. 6, in order to analyse the emission maps for both fuels at default settings of the engine. At the same time, cylinder pressure was recorded at each operating point for further combustion analysis.

At the second phase, the engine was run at 4 steady state operating points with different operating settings in order to examine the simultaneously effect of both EGR and injection timing on combustion and emission characteristics of the engine, in order to explore the potential of HVO in terms of further emission reduction, furthermore the effect of injection pressure as well as the effect of different pilot injection timings were also investigated.

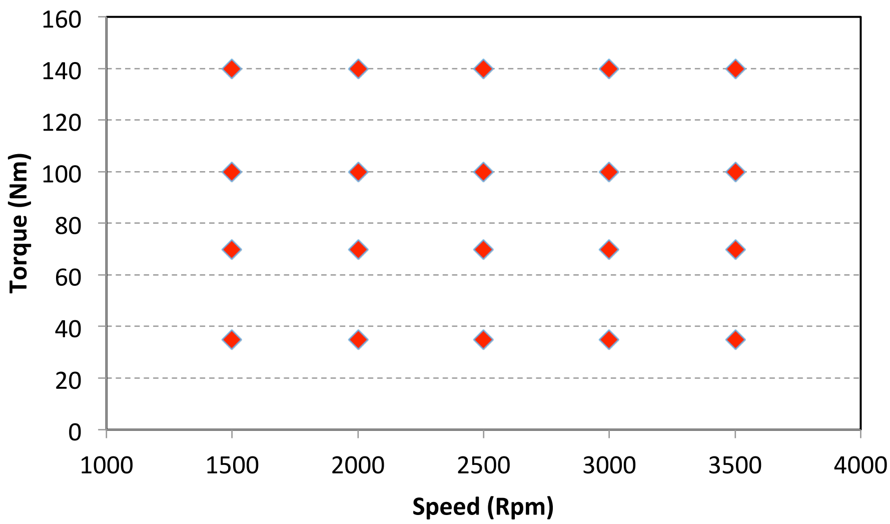

Figure 6 Steady state engine operating points

Week four (21st March – 25th March) Analysis-Evaluation of experimental data.

During the above period, I was taught how to analyse the data from the experimental measurements via Burn Boost software from AVL. This software has the ability to calculate the energy balance as well as the heat release rate of the engine by combined the pressure data as well as the engine setup data from the experiments. Based on this software I was able to generate all the required information during combustion process for both fuels in order to evaluate the effect of different operating settings of the engine.

Description of the main results obtained

Nitric oxide (NOx) and particulate matter (PM) emissions are the main pollutants of diesel engines. According to Fig. 7, HVO reduces NOx and PM emissions compared to market diesel fuel. This can be partly explained by the zero oxygen and aromatic content of the HVO fuel compared to market diesel. Aromatic compounds have higher adiabatic flame temperature and a lower H/C ratio. As aromatic compounds produce higher local combustion temperatures NOx formation is promoted with fuels having higher aromatic content. Moreover PM reduction with HVO fuel is also shown in Fig. 7. Usually, with decreasing NOx concentration (in-cylinder temperature decrease) the PM emissions increases. However the results with HVO fuel show that both soot and NOx emissions are reduced due to simpler molecular chain and higher H/C ratio. The decrease in PM emissions was influenced by the composition of HVO, which contains almost 100% paraffinic hydrocarbons that do not contain aromatic hydrocarbons, sulfur and other mineral impurities that increase PM formation during combustion. Furthermore, the lighter paraffinic hydrocarbons due to the higher cetane number have shorter ignition delay which increases the oxidation time reducing in this way PM emissions. According to the findings, the same trends follow also CO_2, HC and CO emissions, which are lower for HVO fuel in all steady state operating points that were tested.

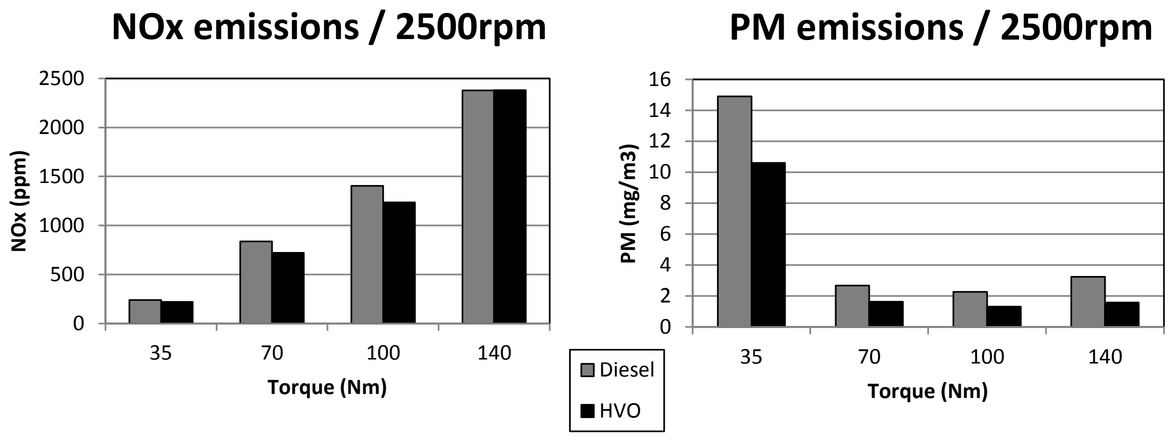

Figure 7 Effect of HVO fuel in PM and NOx emissions

Fig. 8 shows a comparison of gross heat release rate between the engine operating with HVO fuel and the engine operating with market diesel fuel under 1500rpm/70Nm as it was calculated via Burn Boost software. As it was mentioned above HVO fuel has lower density and higher cetane number, as a result the volumetric amount of injected fuel is greater compared to market diesel this result in shorter ignition delay which is confirmed from gross heat release rate. The shorter ignition delay and lower volumetric heating value of HVO could increase the combustion time of the fuel resulting to lower temperature and, thereby, to lower NOx emission. This is because the shorter ignition delay of HVO allows for more air-fuel mixtures in the premixed combustion phase which would ultimately result in a higher peak heat release rate upon ignition. The higher cetane number of HVO fuel and the lower ignition temperature reduces the energy released in the premixed combustion phase which reduces the maximum combustion temperature in the cylinder leading to suppressed NOx formation. Moreover, the shorter ignition delay of HVO fuel results in longer combustion process, thus the oxidation process of the fuel last longer reducing PM, CO and HC emissions as it was already observed from emission measurements. From the results of combustion analysis, it is obvious that HVO fuel reduces NOx and PM emissions simultaneously.

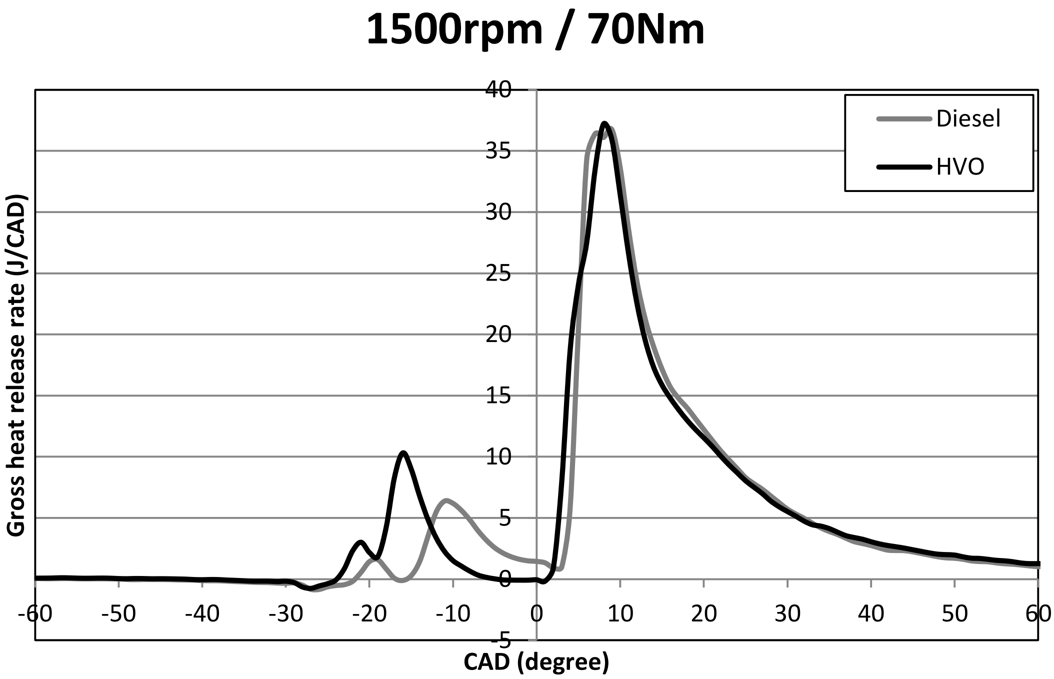

Figure 8 Comparison of gross heat release rate between HVO fuel and market diesel at 1500rpm/70Nm

The effect of different engine strategies on NOx and PM emissions in 1500rpm and 100Nm that were examined are depicted in Fig. 9 and Fig. 10 respectively. It is observed that the adjustment of engine parameters strongly affects both NOx and PM emissions for both tested fuels. However, further evaluation of all the available data from the experiments is needed in order to find the best engine operating strategy for HVO fuel.

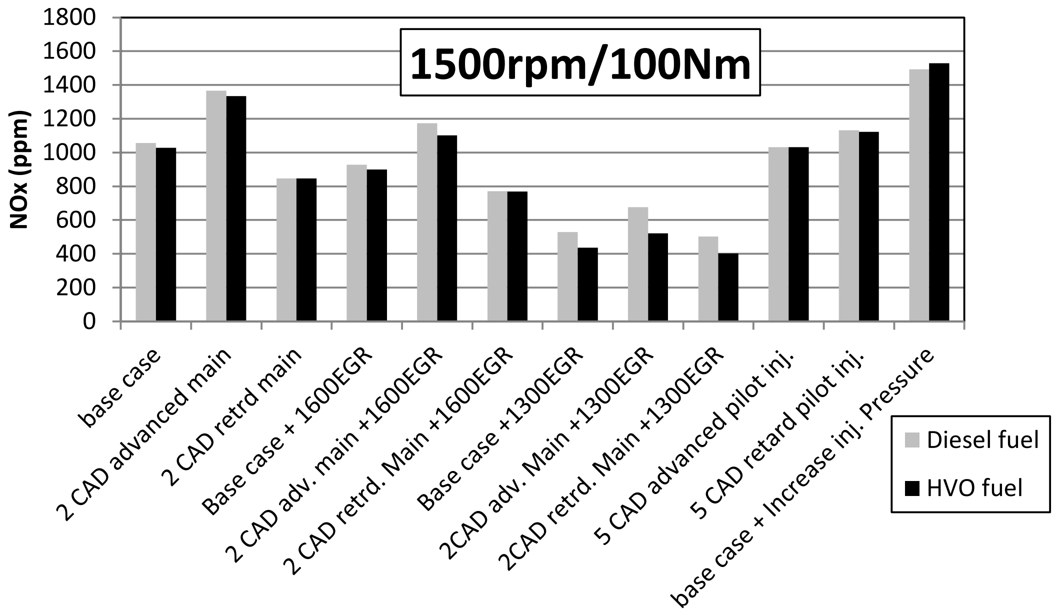

Figure 9 Effect of different engine strategies on NOx emissions

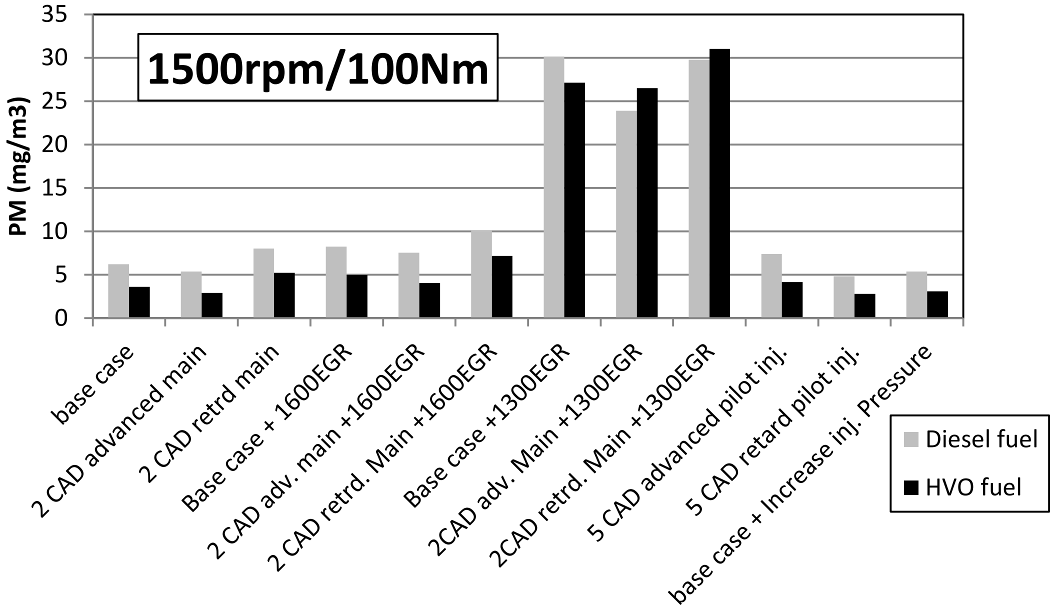

Figure 10 Effect of different engine strategies on PM emissions

Future collaboration with host institution

Both institutions plans to further evaluate all the available results from the current experiments that would lead to a joint paper publication on the role of different operating strategies when the engine is running with HVO fuel.

Confirmation of the Host Institution of the successful execution of the STSM

See attached letter

Other Comments

I sincerely appreciate the COST office for giving me this valuable opportunity to visit the Faculty of Mechanical Engineering at the University of Ljubljana, Slovenia. My thanks also go to my host supervisor, Prof. Tomas Katrasnik and the entire team at the Faculty of Mechanical Engineering for their support. I am also grateful to my home supervisor, Dr. Bezergianni Stella for her support.