Exhaust Emissions from Vehicles Operating on Rapeseed Oil Fuel

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Abstract. One of the primary incentives for expanding the production and use of biofuels worldwide is the potential environmental benefit that can be obtained from replacing petroleum fuels with fuels derived from renewable biomass resources. The use of straight vegetable oil (SVO) in diesel engines is one of the available alternatives, but its use in existing vehicles usually requires modification of engine or fuel system components. In order to find out the trends in changes of different exhaust emission components using fossil diesel and pure rapeseed oil fuel, the car VW GOLF and the truck MAN 19,464 were modified using one-tank and two-tank conversion kits respectively. To ensure stable driving characteristics, a Mustang Chassis Dynamometer MD-1750 was used and for the determination of the content of different exhaust gas components, the AVL SESAM multicomponent exhaust gas measurement system was used. The analyses of obtained results show that the content of NO_x and SO_2 using rapeseed oil fuel in comparison with fossil diesel decreased with both one-tank and two-tank systems. The content of CO and mechanical particles was higher using rapeseed fuel, but the content of unburned hydrocarbons differs depending on the used engine modification system. Since in the one-tank system original engine nozzles were replaced, the pilot studies of the influence of ignition timing on vehicle power characteristics and exhaust emissions were carried out. It was found out that changing the ignition timing from 10.5 to 18.5 degrees decreases the content of CO, mechanical particles and unburned hydrocarbons by up to 70% without losses in power and torque.

Key words: biofuels, straight vegetable oil, rapeseed oil, exhaust emissions, one-tank system, two-tank system

INTRODUCTION

One of the primary incentives for expanding the worldwide production and use of biofuels is the potential environmental benefit that can be obtained from replacing petroleum fuels with fuels derived from renewable biomass resources.

According to the results of the European Commission supported project ‘Clean Views on Clean Fuels’, conventional biofuels, primarily straight vegetable oil (SVO), remain the lowest cost options until 2020 with a gradually increasing market share for future biofuels based on lignocelluloses (Wakker et al., 2005).

The use of SVO in diesel engines usually requires modification of engine or fuel system components. If SVO is to be used in conjunction with diesel in a dual-fuel mode, necessary modifications include additional fuel tank, a system for switching between the two fuels, and a heating system. Another alternative is to use SVO exclusively. Modifications would include an electric pre-heating system for the fuel, an upgraded injection system, and the addition of glow plugs in the combustion chamber as the vegetable oil is not highly flammable.

Examples of investigations in the field of SVO use are researches carried out in Turkey to evaluate the potential of using vegetable oil fuels as a fuel for diesel engines (Altin et al., 2001), emission tests performed on the test bench with rapeseed oil fuelled tractor Deutz-Fahr in Germany (Thuneke, 2006). Comparative bench testing of a direct injection unmodified diesel engine operating on neat rapeseed oil and its blend with petrol was performed in Lithuania (Labeckas & Slavinskas, 2009).

Most of these studies are carried out by testing engines on the bench, but not the entire vehicle. Besides, the results provided by different publications regarding power, fuel consumption and, especially, exhaust gas composition changes are very different. Therefore, an automobile VW GOLF was adapted for using pure rapeseed oil as a fuel at the Scientific Laboratory of Biofuels (Latvia University of Agriculture). The car was modified using ELSBETT one-tank conversion kit (Dukulis et al., 2009a). Methodology for testing automobiles operating on biofuels was developed (Dukulis et al., 2009b). Tests were performed using three different fuels – fossil diesel, biodiesel and pure rapeseed oil, but the first analysis of exhaust emissions using rapeseed oil was not as good as expected (Dukulis et al., 2009c). As one of the most reliable explanations was the use of special oil nozzles (no adjustments were made to the engine during the tests), then one of the tasks for this study is to determine whether the exhaust gas content cannot be improved by changing the ignition timing. To determine whether the previously obtained results were not solely caused by the use of the one-tank system, another vehicle was equipped for using pure rapeseed oil, but this time with a two-tank system.

MATERIALS AND METHODS

Vehicles VW Golf 1.9TDi (rebuilt to run on rapeseed oil with a one-tank system) and MAN 19,464 (rebuilt to run on rapeseed oil with a two-tank system) were used as the study objects in these experiments (Fig. 1).

Fig. 1. Vehicles used in the experiments (VW Golf 1.9TDI and MAN 19,464).

For comparison of exhaust emission content arctic fossil diesel fuel (density at 15° C 826.1 kg m^{-3}, viscosity at 15° C 1.81 m s^{-1}) and pure rapeseed oil (density at 15° C 920.3 kg m^{-3}, viscosity at 15° C 33.63 m s^{-1}) were used in these experiments.

The following measuring systems were chosen for tests (Fig. 2):

- Laboratory Chassis Dynamometer Mustang MD-1750 with Control Platform MDSP-7000;
- Multicomponent Exhaust Gas Measurement System AVL SESAM FTIR (Fourier Transform Infrared Spectroscopy).

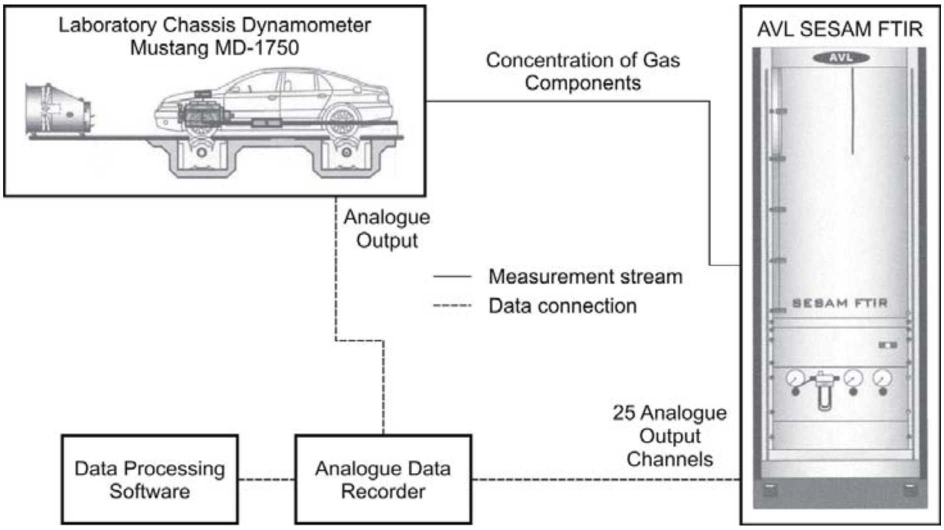

Fig. 2. Block diagram of the emission test routines.

A Mustang Chassis Dynamometer MD-1750 provides the ability to simulate actual road loads while the tested vehicle remains in the safe and controlled confines of a test centre. During Vehicle Simulation test the bench loading motor maintains the load, which corresponds to the real mass of the car and the road and air resistance at a certain speed. This test is typically used for fuel consumption and exhaust component determination at constant speeds. The chosen transmission gear at different speeds for cars equipped with mechanical gearboxes may vary (most often it is 4th or 5th gear), but cars equipped with automatic transmissions must have to have their gear lever put in position 'D' during testing. In these investigations the tests were conducted in idle running and at speeds of 50 and 90 km h^{-1}. They correspond to the maximum allowed speeds in Latvian urban areas and suburbs. Measurements were performed for 60 seconds with the reading step of 1 second. Three repetitions were made in each testing mode.

AVL SESAM (System for Emission Sampling and Measurement) is a multicomponent exhaust gas measurement system that is used particularly in the development of modern engines and vehicles in order to achieve compliance with current and future exhaust gas legislation. By means of absorption of infrared light by the individual gas components, up to 25 gases can be measured simultaneously. In addition, some collective components can be calculated from this process. In these investigations the content of NO_x, CO, CO_2, SO_2, mechanical particles (MP) and unburned hydrocarbons (HC) were analyzed.

RESULTS AND DISCUSSION

The results of exhaust emission analysis for automobile VW Golf 1.9TD are shown in Fig. 3.

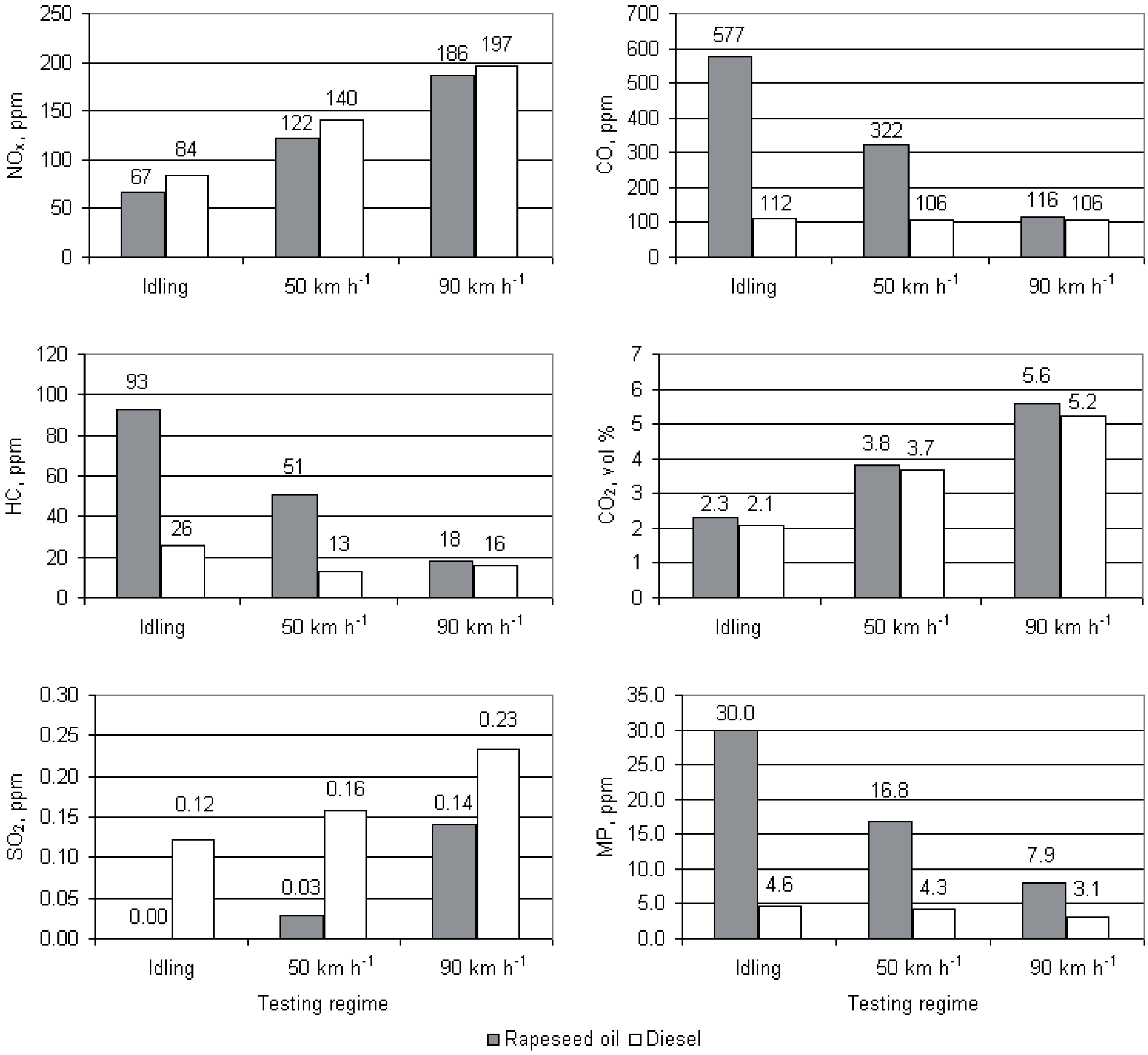

Fig. 3. Exhaust emission comparison of performed VW Golf 1.9TD simulation tests.

In comparison with fossil diesel, the average reduction of NO_x when running on rapeseed oil was 13%. The amount of SO_2 in exhaust gases was also lower by an average of 74%. The CO, HC, CO_2 and mechanical particle (MP) emissions were higher with pure rapeseed oil fuel, compared to fossil diesel fuel. If the CO_2 increase (an average of 7% compared to fossil diesel fuel) is irrelevant, because the plants (in this case, rape) take it back from the atmosphere and consume in growth process providing a neutral carbon circulation in nature, the mechanical particle amount, compared to fossil diesel fuel, increased approximately 3-fold, CO – approximately 2-fold, but the unburned hydrocarbons – nearly 2-fold. The ignition timing in these tests was set as required by the vehicle specification, i.e., 10.5°. As in the publications of other researchers it is mentioned that when using vegetable oil fuels, more complete combustion can be reached by increasing ignition timing, the experiments to determine the ignition timing impact on exhaust gas content were carried out, at the same time measuring the car's dynamic characteristics, i.e., the power and torque. The results of the experiment are given in Table 1. Ignition timing was changed in the range of 10.5° to 21.0°, when, based on the dynamometer readings, the torque and power reduction was observable. The tests were performed in idle running, because the scattering of measured components in this mode was the lowest. In addition to the previously mentioned components the content of methane (CH_4) was also analyzed.

Table 1. The results of optimal ignition timing studies

Ignition timing, degrees	NO_X, ppm	CO, ppm	HC, ppm	CO_2, %	SO_2, ppm	CH_4, ppm	PM, ppm	N_{max}, kW	M, N m
10.5	67.02	577.30	93.84	2.31	0.00	4.39	30.14	38.5	106.0
13.0	70.05	561.23	90.54	2.26	0.00	3.93	28.56	39.0	106.0
15.0	84.66	528.12	75.34	2.28	0.01	3.44	24.12	39.0	106.0
16.5	90.29	515.26	68.53	2.33	0.01	3.10	22.62	39.5	107.5
17.5	131.47	445.63	48.65	2.32	0.02	2.06	14.44	39.5	108.0
18.5	152.20	376.98	33.65	2.36	0.02	1.81	11.00	39.5	108.5
19.5	173.30	418.42	31.88	2.35	0.05	1.64	10.93	39.5	108.5
20.5	189.88	485.12	30.97	2.33	0.07	1.34	8.26	39.0	108.0
21.0	194.90	499.13	28.83	2.40	0.07	1.38	7.67	39.0	107.5

Hence, the optimal ignition timing while running the car VW Golf 1.9TD on rapeseed oil fuel is 18.5°, because here is the peak of power and torque and the minimum of CO content in exhaust gases (reduced about 35% comparing with the 10.5° ignition timing), significantly reduced unburned hydrocarbon (about 66%), methane (59%) and mechanical particle (68%) content. Further increase in ignition timing is not desirable because, as seen from the table, at 19.5° and beyond, the amount of CO and SO_2 is significantly increased, moreover, the more ignition timing is increased; the greater is the NO_x content.

Since in the adapted car, if necessary (for example in winter when operating cars on pure rapeseed oil can be problematic), fossil diesel fuel can also be used, power and torque measurements at fossil diesel fuel and rapeseed oil optimum ignition timings were performed. The results are given in Table 2.

Table 2. The power and torque measurements at different ignition timings

Ignition timing, degrees	N_{max}, kW			M, N m		
	Rapeseed oil after modifying the car	Fossil diesel fuel		Rapeseed oil after modifying the car	Fossil diesel fuel	
		before modifying the car	after modifying the car		before modifying the car	after modifying the car
10.5	38.5	42.0	41.5	106.0	108.0	107.0
18.5	39.5	N/A	42.0	108.5	N/A	107.0

As the table data shows, engine operation with fossil diesel at rapeseed oil optimum ignition timing is not a problem from the viewpoint of power and torque and it even slightly increases power.

The results of exhaust emission analysis for automobile MAN 19,464, rebuilt to run on rapeseed oil with a two-tank system, are shown in Fig. 4.

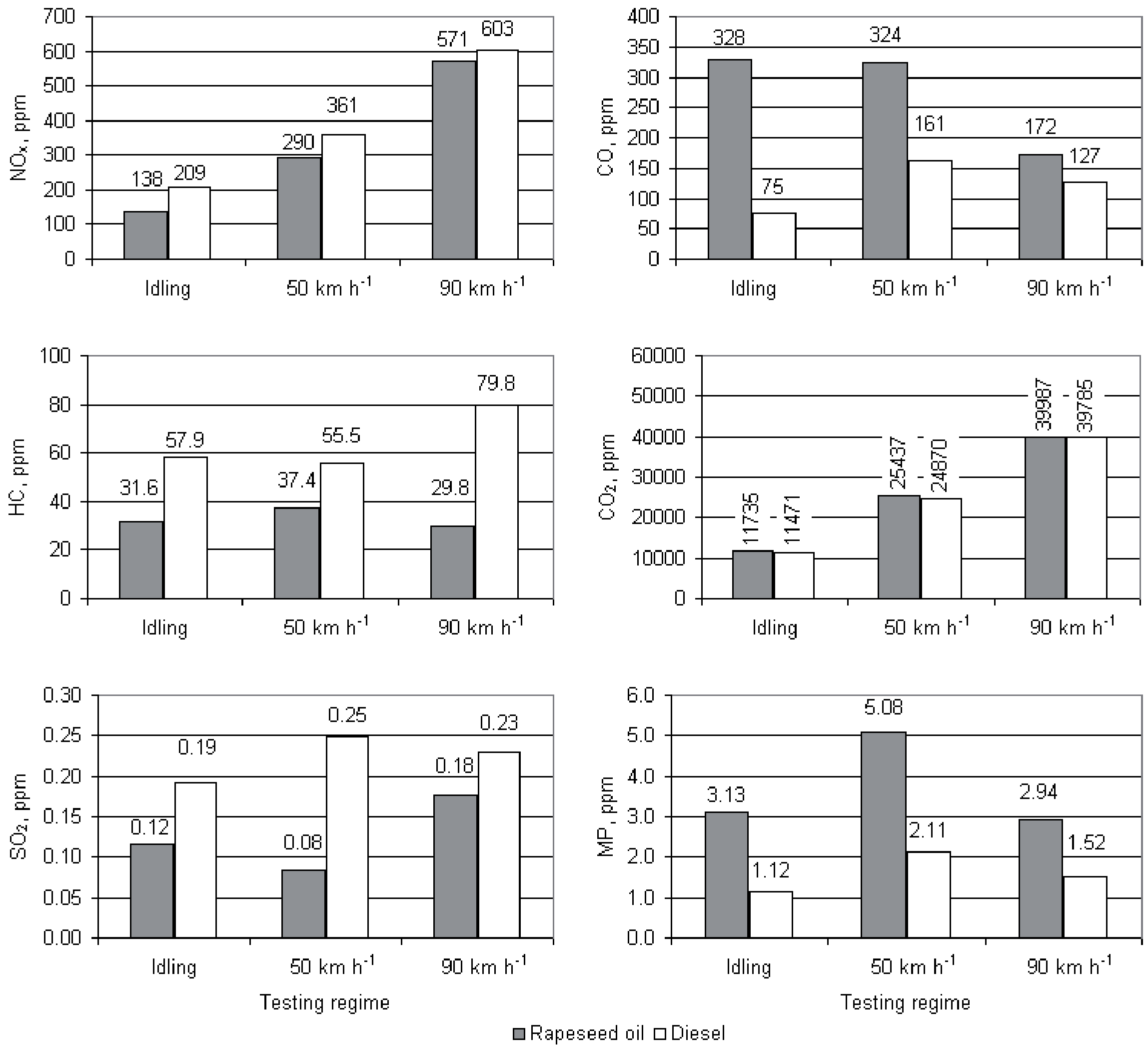

Fig. 4. Exhaust emission comparison of performed MAN 19,464 simulation tests.

Comparing the obtained data with the one-tank system investigations, it can be concluded that the average trends of exhaust component changes are similar:

- NO_x content, using rapeseed oil fuel and the two-tank system compared to fossil diesel fuel, is reduced by 20% (by 13% when using one-tank system);
- SO_2 content decreases by 43% (by 74% when using one-tank system);
- CO_2 content increases by 2% (by 7% when using one-tank system);
- CO content increases 1.6-fold (2-fold when using one-tank system);
- mechanical particle content increases 1.4-fold (almost 3-fold when using one-tank system).

The only exhaust gas component, which changes differently is unburned hydrocarbons. If using one-tank system and rapeseed oil a 2-fold increase compared with fossil diesel was observed, then with two-tank system the content of the unburned hydrocarbons was reduced by 47%.

CONCLUSIONS

1. The trends of different exhaust gas component changes, using rapeseed oil compared with fossil diesel, are similar using both one-tank and two-tank systems.
2. Using a one-tank system the content of different exhaust gas components can be improved by changing ignition timing. However, the reduction of certain components may increase the content of others, such as NO_x.
3. Since not all the contents of harmful components, using SVO fuels, decrease, in order to evaluate the effectiveness of its use, more detailed studies of engine construction and conversion kit impact on exhaust gases have to be carried out.

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