ADAPTING OF AUTOMOBILE VW GOLF FOR USING PURE RAPESEED OIL AS FUEL

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Abstract. The use of straight vegetable oil in diesel engines is one of the available alternatives nowadays how to introduce in practice the EU biofuel Directive with a target of 5.75 % biofuels in 2010, but it usually requires modification of the engine or fuel system components. This article presents adapting of automobile VW GOLF for using pure rapeseed oil as a fuel. The car was modified using the ELSBETT one-tank conversion kit, and the first exploitation tests were carried out in winter time when the air temperature reached -7 °C. Starting the engine and driving in such weather conditions did not cause any problems. Fuel consumption was estimated in two different routes – in intensive traffic conditions in Jelgava city and outside the urban area. The first test results show that pure rapeseed oil fuel consumption is slightly behind fossil diesel, but quite significantly overtakes biodiesel. The modified diesel engine was successfully operated not only with rapeseed oil, but also with fossil diesel and biodiesel, and with various mixtures of these fuels. Analyses of rapeseed oil manufactured in Latvia were performed in Latvia and Germany. They showed that in order to avoid problems of using this oil as a fuel is substantially to control the quality of seeds and pressing process regimes.

Keywords: biofuels, straight vegetable oil (SVO), rapeseed oil, fuel consumption, one-tank system

Introduction

Rapidly growing interest in biofuels is being spurred by the realization that they represent only a large near-term substitute for the petroleum fuels that provide more than 95 % of the world's transportation energy. Today, the question is not whether renewable biofuels will play a significant role in providing energy for transportation, but rather what the implementations of their use will be – for economy, for the environment, for global security, and for the health of societies.

The liquid biofuels most widely used for transport today are ethanol and biodiesel, which can both be used in existing vehicles where ethanol is blended with gasoline and biodiesel is blended with conventional diesel fuel. The use of straight vegetable oil (SVO) and pure biodiesel in diesel engines as well as neat bioethanol in spark-ignition engines are other available alternatives nowadays, but they may require modification of the engine or fuel system components.

Due to SVO relatively high viscosity (approximately 12 times higher than ordinary diesel), using SVO in unmodified engines can result in poor atomization of the fuel in the combustion chamber, incomplete combustion, cooking of the injectors, and accumulation of soot deposits in the piston crown, rings and lubricating oil [1]. In order to run on SVO, these engines must either be refitted (often by attaching a mechanism for pre-heating oil), or they must be dedicated engines, such as the Elsbett engine [2]. Vehicle manufacturers generally will not warranty their engines for operation with SVO. Moreover, development of modern engines has led in the direction of increased electronic engine and combustion control systems, which are generally not compatible with operation using SVO. If SVO is to be used in conjunction with diesel in a dual-fuel mode, necessary modifications include an additional fuel tank for SVO, a system to allow for switching between the two fuels, and a heating system for the SVO tank and lines if the vehicle operates in low temperatures. Under this configuration, the engine started on diesel and switched over to SVO as soon as it is warmed up. It is then switched back to diesel shortly before being turned off to ensure that it contains no SVO when it is restarted. Another alternative is to use SVO exclusively. Modifications would include an electric pre-heating system for the fuel (including lines and filters), an upgraded injection system, and the addition of glow plugs in the combustion chamber since vegetable oil is not highly flammable. The modification can be expensive, reaching a cost of € 2 000 or more [1].

The EU biofuels market, under the biofuels Directive with an extrapolated target of 20 % biofuels in 2030 [3], has been modelled with the BIOTRANS model with the aim to conduct quantitative analyses on the production and costs of biofuels, and on the resulting market structure and supply chains. According to the BIOTRANS analysis, of the conventional biofuels PVO proves to be the lowest cost option compared to biodiesel and bioethanol, even with the necessary cost of vehicle adaptation (Table 1) [4].

Table 1

Lowest cost biofuel mix up to 2030

Biofuel	2005	2010	2015	2020	2025	2030
PVO	90 %	80 %	70 %	50 %	41 %	20 %
Biodiesel	10 %	3 %	4 %	4 %	4 %	4 %
Bio-DME		1 %	2 %	20 %	30 %	53 %
Biomethanol		6 %	14 %	15 %	15 %	14 %
CSNG		10 %	10 %	11 %	10 %	9 %

The key message is that in order to reach the 5.75 % target in 2010 a 100 % use of PVO and biodiesel exclusively for the diesel fleet of vehicles would be more cost-efficient than the use of E-05 bioethanol for the petrol fleet. The BIOTRANS model predicts that after 2010 the fraction of PVO – and in practise also biodiesel – in the biofuel mix decreases in favour of that of advanced biofuels. The reason for this is that in order to achieve increasing biofuel targets less attractive potentials (less suitable land for crop production) for PVO and biodiesel would have to be used, which leads to higher costs for these fuels. If PVO and biodiesel become more expensive, the use of advanced biofuels may become economically attractive, when they are available.

Rapeseed oil as fuel in Latvia by the law was approved in May 2006, and it can be used in diesel engines considering certain emission requirements. The rapeseed oil quality requirements are set down by the Cabinet of Ministers regulations No. 515, which were enforced in July 2007. These norms are based on the German Quality Standard for Rapeseed Oil as a Fuel (RK-Qualitätsstandard) [5]. The main properties defined by the standard are the density, flash point, kinematic viscosity, carbon residue, iodine number, and the sulphur content, but limiting values are determined for the contamination, acid value, oxidation stability, and the content of phosphorus, ash, and water.

The most experienced country in the use of biofuels is Germany where over 50 companies offer adaptation technique for rapeseed oil fuel. Adaptation costs vary from € 1 000 to € 7 000. Adapted engines are used in cars, busses, trucks, tractors, agricultural and construction machinery, stationary engines, boats, trains, etc. Far more than 12 000 adapted engines are operated with rapeseed oil. Emission tests with rapeseed fuelled tractor Deutz-Fahr (162 PS) on the test bench show that limiting values of CO, HC and particulate matter of EURO norms for rapeseed oil and diesel fuel are met, but emission of NO_x with rapeseed oil fuel is up to 14 % higher than the limiting value [6].

Considering, that at the Scientific Laboratory of Biofuels (Latvia University of Agriculture) very qualitative laboratory equipment, for example, the laboratory chassis dynamometer MD-1750, fuel consumption meter AVL KMA Mobile, and the SESAM FTIR system for measuring emissions in exhaust gases, is available, as well as the fact that in cooperation with the limited company IECAVNIEKS studies of the MAN TGA 18.410 exploitation, using the pure rapeseed oil and a two-tank system recently were carried out, it was decided to modify a passenger car to run on pure rapeseed oil, but using a one-tank system. The one-tank choice was based on the fact that in the passenger car facilities to install a second tank without taking up much room at the baggage compartment are limited. In addition, the excess weight carriage would lead to increased fuel consumption and reduction of dynamic performance. Moreover, in many countries (including Latvia) the second fuel tank is classified as a modification, which requires a special certification for the car to successfully pass the roadworthiness test. Exploring possibilities for starting the car in winter conditions and ascertainment whether the oil produced in Latvia meets the standard requirements were set as the subordinate objectives of this investigation.

Materials and methods

Dealing with the problem to rebuild the car, the proposed conversion components of companies ATG [7], ELSBETT [8], GREENBULL [9], and RMG RAPSOL [10] were investigated. The choice was made for the benefit of the firm ELSBETT that in the one-tank use area they have the longest experience, and the fact that the company offers a specially developed nozzle design. The fuel using the ELSBETT nozzles is injected locally and tangentially inside the central combustion area within the chamber. This process prevents the fuel and its residue from making contact with the walls, thus minimizing the loss of heat. For this reason the injection nozzles have one aperture with a self-cleaning needle, and are arranged in a specific position and at a specific angle.

The typical one-tank conversion kit would contain the following parts (Fig. 1):

- injector components;
- glow-plugs;
- additional fuel filter;
- sometimes additional fuel pump;
- coolant-water heat exchanger;
- electrical fuel heater/filter;
- temperature switch;
- cut-off valve;
- relays and sockets;
- fuel and water pipes;
- fuel hand pump;
- cabling.

Fig. 1. **The typical 1-tank conversion kit components**

The cars that can be modified to run on rapeseed oil using ELSBETT one-tank sets are summarized in Table 2.

Table 2

The most popular cars, which can be modified using a one-tank system

Car	Diesel engine volume	Production years	Fuel system
Land-rover cars			
BMW X 5	3.0	2000 – 2003	BOSCH
CHRYSLER JEEP CHEROKEE	2.0 – 2.5	1984 – 2001	BOSCH
CHRYSLER JEEP GRAND CHEROKEE	2.5 – 3.0	1997 – 2005	BOSCH
FORD MAVERICK	2.7	1993 – 1998	BOSCH
MITSUBISHI PAJERO	2.5	1991 – 2005	DIESEL KIKI
NISSAN PATROL	2.8 – 4.2	1987 – 2000	BOSCH KIKI
TOYOTA LANDCRUISER	2.4 – 4.2	1980 – 2002	DENSO
Passenger cars			
AUDI 80	1.6 – 1.9	1982 – 1996	BOSCH
AUDI 100	2.4 – 2.5	1982 – 1997	BOSCH
BMW	1.8 – 2.5	1983 – 2000	BOSCH
CITROEN	1.9	1998 – 2002	BOSCH
FIAT	1.7 – 1.9	1987 – 1995	BOSCH
FORD	1.6 – 1.8	1993 – 1998	BOSCH
LADA NIVA	1.9	1994 – 2000	BOSCH
MERCEDES BENZ		1961 – 2001	BOSCH
MITSUBISHI	1.8 – 2.3	1988 – 2003	NIPPON DENSO
WOLKSWAGEN	1.9	1985 – 2006	BOSCH

VW Golf 1.9TD was chosen for reconstruction. As a basis for selecting this car served the fact that it is, though not very new, but still quite widespread in Latvia (also called peoples' car). Besides that, the same engine is used in cars AUDI 80, SEAT CORDOBA, SEAT IBIZA, SEAT TOLEDO, VW PASSAT and VW VENTO, that raises the representativeness of the selected engine.

The car adapting starts with the fuel hose test. The internal diameter has to be not less than 8 mm for the unrestricted free flow of rapeseed oil. Other adaptation actions are carried out in the engine compartment of the car, where the place of the heat exchanger and the heated fuel filter has to be selected. It is preferable to designate these places so that the potential heat losses would be smaller. So the heat exchanger should be closer to the cabin heater hoses. In turn, the heated fuel filter has to be as near as possible to the heat exchanger, in order that the warmed rapeseed oil does not get cool when it reached the filter. Balanced and efficient operation of the heat exchanger and fuel filter allows faster interrupting electrical heating of the fuel filter. The manual fuel pump is installed in the fuel line before the heat exchanger. With this pump the fuel system is bleeded after the filter replacement. The original fuel filter is included into the backup line and, using the valve, it can be engaged in the case, when the first filter blocks, as well as for making easier the flow through the filters after the engine warm-up (Fig. 2). Finally, the nozzles and glow plugs have to be replaced.

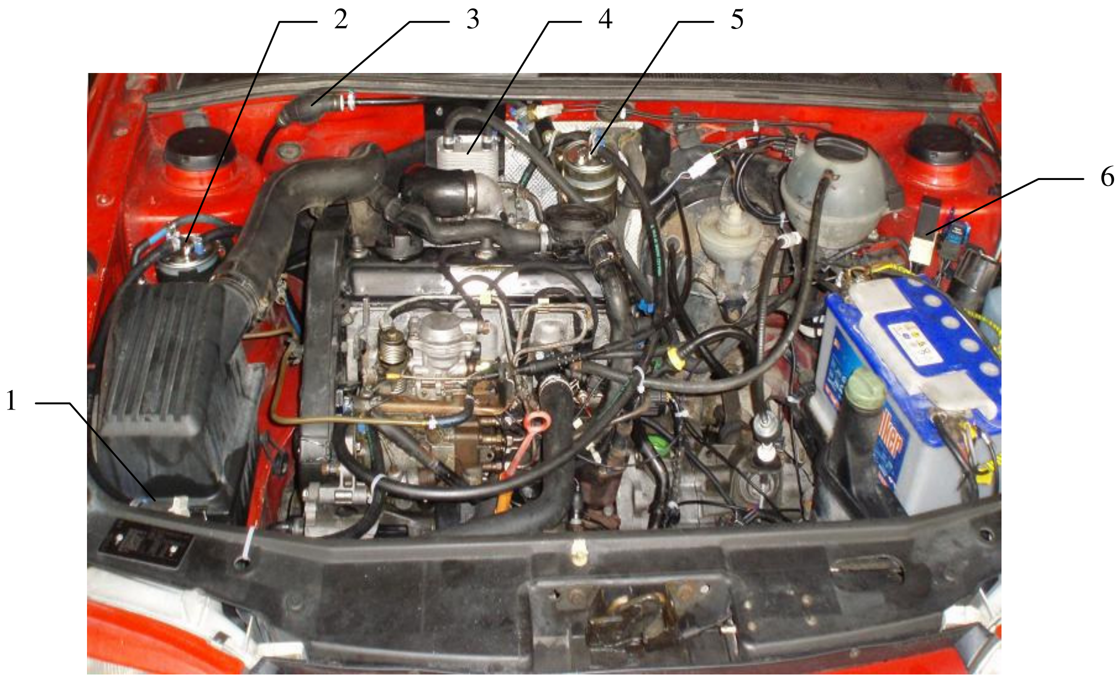

Fig. 2. **Displacement of one-tank system components in engine compartment**: 1 – valve; 2 – original fuel filter; 3 – fuel hand pump; 4 – heat exchanger; 5 – fuel heater/filter; 6 – relays

When the fuel system conversion was finished, the fuel tank of the car was filled by rapeseed oil (Fig. 3). The first experiments were carried out in winter conditions (Fig. 4).

Fig. 3. **Filling the car with pure rapeseed oil**

Fig. 4. **Car before the first experiments**

Starting the engine the smell of baked potato was felt, but the exhaust gases were colorless. The surprise was also the fact, that changing the cold engine revolutions, the soot emissions on the snow were not visible. The engine was started at different temperatures below zero, and using infrared thermometer SMART SENSOR AR 300 temperature measurements of the various fuel system components were performed during the engine warm-up. The results are summarized in Table 3.

The driving tests 3 to 8 minutes after the engine starts were also performed with increments of 1 minute. Significant differences in comparison to operation with fossil diesel fuel were not observed, because the electric heater, new nozzles and glow plugs provided the oil heating and smooth operation even when the engine was not yet warmed up.

Table 3

Fuel system component temperature measurements after 25 minutes engine idling operation

Measured parameter	Test No. 1	Test No. 2	Test No. 3
Air temperature, °C	-1.4	-5.2	-7.1
Cold engine temperature, °C	-1.6	-5.3	-7.0
Electric heater heating time up to 60 °C, min	1.5	1.7	1.7
Coolant temperature, when the electric heater turns off, °C	69.1	69.8	70.1
Fuel heat exchanger temperature, °C	59.0	57.2	56.2
Fuel filter temperature, °C	54.8	56.2	52.3
Temperature at the high pressure pump, °C	54.1	55.9	50.5

Driving the car in an urban area, as well as outside the city, the horsepower reduction was not noticed, but further experiments require more precise measurements on the laboratory chassis dynamometer. To obtain the first comparative results of the fuel consumption, the car was equipped with a fuel consumption meter at the baggage compartment (Fig. 5).

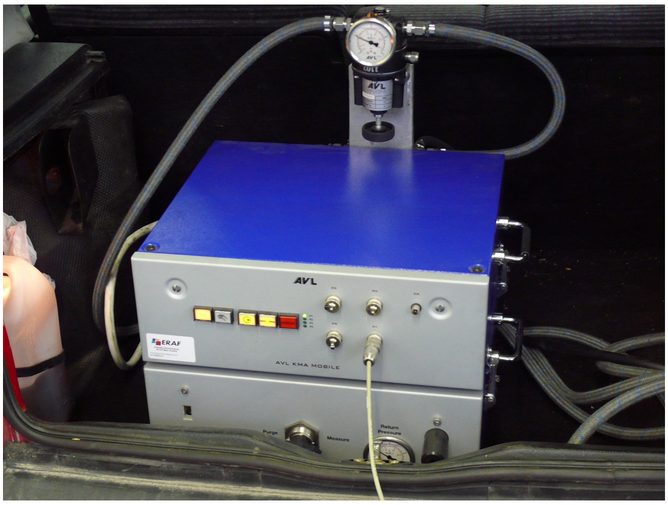

Fig. 5. **Fuel consumption meter AVL KMA Mobile**

Results and discussion

Since this car before conversion was tested in real road experiments using fossil diesel and biodiesel, the same parameters were determined also using rapeseed oil as a fuel.

The fuel consumption was estimated in two different routes – in intensive traffic conditions in Jelgava city and outside the urban area. In the first selected route (Fig. 6) 15 drive repetitions using each fuel were made. Three trips with the highest speed curves correlations were selected for comparison. Driving tests were only conducted during normal working days' peak hours (8:00 – 9:30 and 11:30 – 13:30), excluding the public holidays. The second route (Jelgava – Tukums – Engure – Rindzele – Engure – Tukums – Jelgava) included driving in the cities (Jelgava and Tukums), non-urban area, as well as driving through small villages. As the total route distance was large (approximately 176 km), then 3 drive repetitions with each fuel type were conducted.

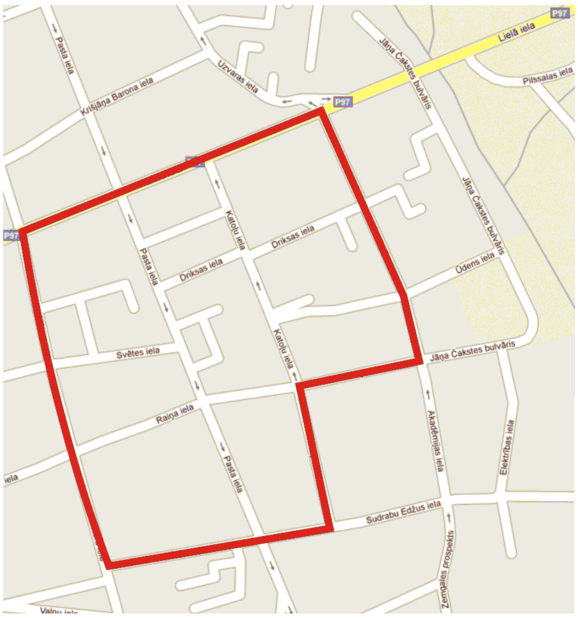

Fig. 6. **Driving route in Jelgava**

The results of the tests are given in Table 4.

Table 4

Fuel consumption test results

Parameters	Fossil diesel	Biodiesel	Pure rapeseed oil
City driving route			
Average distance, km	2.36	2.35	2.36
Average speed, km h^{-1}	23.36	23.16	23.26
Average fuel consumption per 100 km, l	9.67	10.65	9.72
Combined driving route			
Average distance, km	175.50	176.12	176.23
Average speed, km h^{-1}	72.04	72.26	72.19
Average fuel consumption per 100 km, l	6.55	6.76	6.57

The first results show that pure rapeseed oil fuel consumption is slightly behind fossil diesel, but quite significantly overtakes biodiesel. However, objectively only the first two types of fuel could be compared, because using rapeseed oil, the car was modified, i.e., different nozzles and glow plugs were used. Therefore, a behavior of a modified engine with fossil diesel and biodiesel has to be established in future experiments. Of course, performing real road tests, there is appreciable scattering in the results between repetitions, that is why it is necessary to carry out experiments on the laboratory chassis dynamometer, simulating real driving conditions in the different modes. It should be noted that even after rebuilding the car could run without problems with fossil diesel and biodiesel, but then the electric heating filter and the heat exchanger were switched off.

The home pages of the above mentioned conversion kit manufacturing companies contain information on cars that are operated with pure rapeseed oil – the driven kilometers, the number of refusals, their reasons, etc. The analyses of these refusals show that a great attention should be paid to the used oil quality, which is highly dependent on the seed quality and the compliance of oil pressing process regimes. Therefore, in cooperation with the limited company LOGINS & CO independent analyses of oil samples were carried out in Latvia (Ventspils) and Germany. The tested oil was pressed from the seeds, which were purchased in two different firms, which here are named as “Company X” and “Company Y”. Oil extraction was done using the FARMET presses, but the same pressing process regimes were provided using an automatic control system, which was managed from the computer. The results of the received analyses are summarized in Table 5. For comparison, the standard limiting values are also shown.

Table 5

Results of oil sample laboratory analyses

Determined index	Testing results		Limiting values	
	Oil pressed from the seeds purchased in “Company X”	Oil pressed from the seeds purchased in “Company Y”	min	max
Water content, % m m^{-1}	0.08	0.08	N/A	0.075
Total contamination, mg kg^{-1}	46	18	N/A	24
Phosphorus content, mg kg^{-1}	11.7	42.6	N/A	12 (20*)
Sulphur content, mg kg^{-1}	1.9	2.0	N/A	20
Iodine value, g J_2 per 100 g	111	114	95	125
Kinematic viscosity, $mm^2\ s^{-1}$ at 40 °C	33.63	36.57	N/A	36 (38*)
Density at 15 °C, g m^{-3}	920.3	920.4	900	930

* – *Permitted in Latvia until January 2010*

As it can be seen from the Table 5, in oil samples from the seeds purchased in “Company X” nonconformity is observed in total contamination quantity, but from the seeds purchased in “Company Y” the phosphorus content does not meet the requirements. This can cause blocking of the fuel filter (swelling of phosphorus lipids), deposits on valves and pistons, contamination of catalysts, and ash deposits in the particle filter. These analyses show that regardless that the oil by the law is approved as a fuel in Latvia, its commercial realization in fuel filling stations can not be started until all quality requirements are guaranteed. Similarly, the oil production companies and farmers that already use oil as a fuel for their motor vehicles, have to be very careful, because the poor seed quality, non-compliance of optimal harvesting, seed processing or pressing regimes can led to engine damage, which require large expenditures. As the German experience shows, these problems can be solved by after treatment of the extracted oil.

Conclusions

1. Performing the modifying of the car for running on rapeseed oil as a fuel, it was found that a user with the engineering experience can easily obtain the necessary fuel system components and make conversion under one's own steam.
2. The first studies of the passenger car running on rapeseed oil as a fuel in winter conditions show that exploitation even when the air temperature reached -7 °C did not cause any problems. If the temperature becomes lower, it is advisable to add the winter biodiesel to the oil so much that rapeseed oil has to free flow out from the fuel tank.
3. Modified diesel engines can be operated not only with rapeseed oil, but also with fossil diesel and biodiesel, or with various mixtures of these fuels. So just which of these fuels can be cheaper to buy, it can be used to run diesel engines.
4. First test results show that pure rapeseed oil fuel consumption is slightly behind fossil diesel, but quite significantly overtakes biodiesel. However, objectively only the fossil diesel and biodiesel fuel consumption results could be compared, because using rapeseed oil, the car was modified. Therefore, the behavior of a modified engine with fossil diesel and biodiesel has to be established in future experiments.
5. Analyses of rapeseed oil manufactured in Latvia showed that, in order to avoid the problems of using this oil as a fuel from both a technical and legislative point of view, it is substantially to control the quality of seeds and pressing process regimes.

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