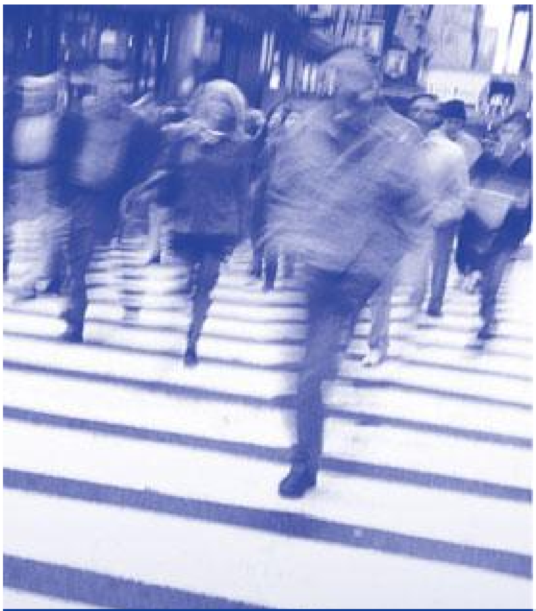

CiViTAS
Cleaner and better transport in cities

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Data collection on modified engines on pure plant oil

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CONTENT

1. INTRODUCTION

Carbon dioxide produced at combustion of biomass does not contribute to the pollution of the environment with gases producing the greenhouse gas effect. Biomass produced in agriculture is used as the source of nutrition for humans and animals, for the processing in different raw materials for clothes and other products, and fuels; one part of it, in the form of organic wastes, returns directly into the soil. Beside solid and liquid biomass products, biomass provides liquid fuels or biofuels. They can be used as replacement or addition to fuels originating from oil, in transport and in various areas of human activities. Among liquid fuels from biomass the following fuels are the most important currently: bioethanol, biomethanol, plant oil and biodiesel. Recently, beside biodiesel used for driving of diesel engines of different vehicles and working machines, plant oil which in its refined or non-refined form can be used for driving of modified engines has been gaining on importance. Energetic usage of plant oil in engines (diesel engines of working machines, tractors, trucks, municipal vehicles, cogeneration units for the production of electric and thermal energy, etc.) is the actual alternative for the current fossil fuels (diesel fuel of mineral origin). Plant oil as an energy source is becoming more and more interesting due to permanent increase of fossil fuel prices and problems concerning the environmental protection with which the mankind is increasingly facing. It is of major importance that plant oil produced from oil producing plants is available practically in the entire Europe. Northern parts of Europe are more convenient for the production of oilseed rape and the southern ones for the production of sunflowers, soybean, etc. In other parts of the world, palm trees, jatropa, etc. are used for oil production. There are many plant species in the world, from which plant oil can be made. Plant oils are part of solar energy stored by means of natural processes going on in the plant itself.

Oils used for purposes mentioned above may be produced by mechanical process of extraction – pressing, or industrially – extraction by means of solvents. The process of oil production by means of pressing does not demand complicated machines as compared with the industrial process of oil production with extraction using solvents. Distinctive features of mechanical pressing process are low energy consumption and zero chemicals for extraction (ecologically controversial). Machines used for mechanical pressing of oil work continuously and do not require any special engagement of labour force. Recently, Slovenia has been witnessing great changes in the field of biofuels as a consequence regarding the need for certain degree of self-supply with energy, environmental protection and inclusion of field crop production in the biofuel production processes. In frame of strategic goal of Slovenia to increase the degree of self-supply with energy, field crop production could play an important role in the field of alternative energy sources, especially in biofuels made from oilseed rape.

2. DECENTRALISED UNITS PRODUCING PURE PLANT OIL

Decentralised producers of oil intended for direct use in remodelled diesel engines or for further processing in biodiesel fuel have been spreading in the world and in EU countries recently which is the result of oil production by means of mechanical pressing in frame of small production units. Decentralised oil production stands for pressing from 0.1 to 5 t seed/day by oil plant seed processing units (in some countries the production limit denotes the capacity of 25 t seed/day, f. ex.: in Denmark).

2.1 Advantages of decentralised units for plant oil production

Decentralised production units can work economically and environmentally friendly since their technical equipment and work process are very simple and require low use of energy (80 kWh/t of processed seeds). Decentralised oil production uses 6 times less energy on the average than the industrial oil production. This type of oil production has also other important advantages such as: it is performed near the locations of agricultural production, it is directly or indirectly connected with the agricultural production itself (no intermediaries), investment costs in equipment are low, there are no waste waters, high flexibility of production (quick transfer to pressing of other types of oil seed, f. ex.: for consumers' use, which increases the utilisation rate of the machine), shorter transport distances (up to 30 km from the production site) resulting in lower costs, it provides higher added value to agriculture of certain area, by-product produced at mechanical extraction is oilseed cake used for animal

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food has high nutritive value (it contains 12 – 17 % of oil in contrast to industrial cake which contains less than 1 % of oil). The economy of such production is determined by the structure of market in the sense of raw material supply and the possibility of acceptance of products (oil and oilseed cake).

2.2 Decentralised units for the production of plant oil in Slovenia

For the Slovene territory we prefer a decentralised form of oil production for direct use or further esterification for biodiesel fuel in special production units (pressing capacity 0.1 t/day to 5 t/day), which may be placed on different locations over the country (the importance of fragmentation of production units).

A producer who is going to press the oilseed rape for biodiesel on his own farm could earn extra income which would mean an additional motivation for a more extensive production of oilseed rape and spreading of decentralised type of oil production on the territory of Slovenia. The oil pressed may also be used as direct source of energy on the farm itself.

2.3 The quality of oil

Quality plant oil used for driving of engines or esterification to biodiesel should have as low phosphorus content (below 10 mg/kg) and solid particles (impurities) as possible. Too high phosphorus content in plant oil and in biodiesel made of plant oil has a negative influence on the combustion in engine. The results of tests conducted in Germany have shown that the content of phosphorus in oil produced by cold pressing may be below 10 mg/kg which is an additional advantage in favour of decentralised oil production.

At the cold pressing the majority of phosphorus found in seed passes into oilseed cake and not into oil. This is a great advantage of cold pressing in comparison with industrial heat method in which the high content of phosphorus in oil should be lowered by means of costly refinement.

3. DEVELOPMENT OF DIESEL ENGINES DRIVEN BY PLANT OIL

Diesel engine got its name after its inventor (Rudolf Diesel, 1858 – 1913) who developed the engine in 1892. Diesel's basic idea was to use coal dust available in large quantities for driving of engines. Since the tests with coal dust did not prove successful on his engine, Diesel started testing other liquid fuels. He used different oil fractions and plant oils in his tests. As a curiosity it has to be mentioned that he presented already at the World Fair in Paris in 1900 an engine which used peanut oil for driving. This idea came from the French Government which was looking for an option of producing fuel in their African colonies, Mitelbach et al. (1). They engaged Diesel who started experimenting with his engine which used different plant oils as fuel. Diesel declared in 1911 "My engine can use different plant oils which may greatly contribute to the development of agriculture". In 1912 he said visionary words "The use of plant oils for engine driving may seem insignificant at the moment but in the future these oils will be as important as oil and coal are today". Other European countries followed the example of France, for instance: Belgium, Italy, Germany and Great Britain. In the period between two World Wars when oil derivatives were cheap, the interest for plant oil as an energy source fell to its minimum once again. The interest in this fuel increased again during the World War II due to lack of oil derivatives. After the World War II the interest fell down to zero to awaken at the beginning of the seventies of the past century after the first oil crisis. Beside this problem the scientists began to warn the public about negative consequences of global heating due to the increasing use of fossil fuels for different activities of mankind. Additionally, in developed European countries great food surpluses occurred so that it was necessary to find additional incentives for field crop production. The solution appeared in the form of long forgotten plant oil made from various oil plants that could be used for driving of diesel engines. We are witnessing the visionary words of the father of diesel engine to have come true, i.e. the plant oils for energetic purposes have finally gained on importance at the end of the twentieth and at the beginning of the twenty-first century.

Recent pioneer in the field of adjustment of diesel engines to plant oil was the German firm Elsbett which, at the beginning of the seventies of the last century, offered the first engine adapted to the use of plant oil to German market. The engine had a special shape of the combustion chamber (spherical shape) in the piston, special high-pressure injection nozzles which injected the fuel in the center of the chamber in piston, heating of plant oil in order to reduce its viscosity, etc. The firm built such engines into different motor vehicles. The problem was high price of the engine so that in the period of relatively cheap oil derivatives buyers were not particularly interested in using them. The firm sold the production technology of such engines to China. Today, Elsbett's activities consist of production of special sets used for modification of the existing diesel engines in cars and trucks, construction machinery, tractors, etc. Beside the firm mentioned above there are some tens of firms dealing with the same business in Germany today. Similar firms were founded in other European countries and the United States. The manufacturers found out that it was reasonable to modify the already existing engines because this was the cheapest solution for the user as it allowed immediate exploitation of alternative energy source.

3.1 ENERGETIC ADVANTAGE OF PLANT OIL AS ENERGY SOURCE

- Diversification and increase of possible alternative to fuels for the production of thermal power
- Liquid fuel of high energetic value which can be produced by a simple process of mechanical extraction from oil plant seed (pressing of oil plant seed using oil plant presses)
- Technology of oil production using the process of mechanical extraction in the price class available to a broad circle of users (low cost technology)
- Low energy consumption for the production of pure plant oil from oil plant seed (lower energy consumption in comparison with the production of biodiesel or bioethanol)
- Accessible to family farms which produce oilseed rape or other oil plants and pursue the process of cold pressing of oil
- The price of pure plant oil is interesting (it ranges from 0.65 – 0.9 EUR/l in EU)
- At decentralised oil production for energetic purpose by cold or hot pressing of oil plant seed, fodder for animal nutrition (oil meal or pellets) comes out as by-product
- Low transportation costs of fuel due to local production

3.2 ECOLOGIC ADVANTAGES OF PLANT OIL AS ENERGY SOURCE

- Renewable energy source
- Closed CO_2 circle
- Biodegradable (in case of spilling on ground 99 % of it is degraded in three weeks)
- Non-toxic (no danger of inhaling toxic or carcinogenic gases due to combustion, no danger at the contact with skin)
- Minimum pollution of the environment in case of spilling during transportation and manipulation (0 class with regard to water pollution)
- Reduced emissions of greenhouse gases CO_2, CO, PAH, hydrocarbon, etc. at combustion in diesel engines
- No sulphur emission

- Emissions of solid parts are reduced by 50 – 70 % in comparison with mineral diesel fuel
- Complete combustion due to higher quantity of O_2 in fuel (no black smoke coming from exhaust pipe at overloading of engine)
- Does not evaporate in the air like mineral fuels
- Simple manufacturing (no chemical processing)
- Hardly flammable (safe for manipulation, transport and storage due to high combustion temperature)
- Fuel is transported on the local basis and not from faraway places in the world, consequently, lesser pollution of the environment due to shorter transport distances of fuel.

3.3 ECONOMIC ADVANTAGES OF PLANT OIL AS ENERGY SOURCE

- Inclusion of field crop production in the energy supplying chain
- Oil by-product is used for animal nutrition (lesser dependence on fodder import from abroad), better supply of fodder on the national market means lower food (meat) prices
- Opening new jobs in field crop production and in processing industry
- New solutions in the field of diesel engines and their new construction for driving with plant oils signify a possibility of opening new jobs in industry and other activities

3.4 ADVANTAGES OF DECENTRALISED PRODUCTION OF OIL PLANTS FOR ENERGETIC PURPOSES IN THE FIELD CROP PRODUCTION

- By-product used for animal nutrition or as energy source
- Utilisation of land in the phase of overgrowing for the production of oilseed rape
- Possibility of oilseed rape production on obligatory fallow fields (the current EU field crop production policy but it is unknown whether this option will be enforced in future)
- Subsidies for energetic seeded crops in EU (oilseed rape, sunflowers, etc.)
- Oilseed rape is important for crop rotation
- High nutritive value of oil meal from oilseed rape seed (in meal there are 10-17% of oil at cold pressing)

3.5 THE QUALITY OP PLANT OIL

Different from biodiesel which was standardised in EU, plant oil has not yet been standardised as fuel. Following the initiative of some institutions and manufacturers from EU, a proposal of standard for plant oil from oilseed rape intended for energetic purpose was prepared. The quality plant oil for diesel engines has to have the lowest possible phosphorus content (below 15 mg/kg) and that of solid particles (impurities). Phosphorus is present in the form of phosphorus lipids. Higher quantity of phosphorus augments the possibility of oil oxidation and water binding and, consequently, higher quantity of water in oil. A too high quantity of phosphorus in plant oil and biodiesel from plant oil affects negatively the combustion process in engine (plaques occurring in the combustion chamber of the engine). The results of an experiment conducted in Germany indicated that the quantity of phosphorus in oil obtained by cold pressing ranges below 10 mg/kg oil (additional advantage speaking in favour of decentralised oil production). At cold pressing, the majority of phosphorus in seed passes into oil meal. This is a great advantage of cold pressing in comparison with the industrial process where high quantity of phosphorus in oil has to be reduced by high price refinement. The reduction of phosphorus quantity at pressing may be influenced by using as low a number of rotations of pressing part as possible and a slightly higher temperature of seed to be pressed.

Table 1: Characteristics of mineral diesel fuel, oil from oilseed rape and methyl ester of oilseed rape (biodiesel)

	Measure unit	Mineral diesel fuel	Rapeseed oil	Methyl ester of rapeseed oil (biodiesel)
Heating value	MJ/kg	42	39,4	40,5
Density at 20°C	kg/dm^3	0,83	0,91	0,88
Heating value (volume)	MJ/l	34,44	36,14	35,84
Viscosity at 20°C	mm^2/s	2-3	32	3,5-5
Flame point	°C	74	> 220	> 100

3.6 DIESEL ENGINES RUNNING ON PLANT OIL

For the running of diesel engines, biodiesel produced by the process of esterification of different plant oils (in the process of esterification, methanol or ethanol are added to plant oil in the presence of catalyst; in EU, for the process of esterification, oil obtained by mechanical extraction of oilseed rape or sunflower is used in most cases) or plant oil may be used. In the first case no special modifications of diesel engines are required and in the second case the fuel supply system in diesel engines has to be adjusted.

All positive characteristics of plant oils for energetic purposes were used by leading European manufacturers of engines and tractors. Diesel engine running by plant oil has been in the serial offer of the engine producer Deutz AG since 2007. The manufacturers Fendt and Same-Deutz Fahr started to build in their engines in their tractors. Fendt's concept of tractor which uses plant oil as fuel was developed in co-operation with the engine manufacturer Deutz AG and it is based on the two-tank system connected with electromagnetic valve for the guidance of fuel from one or the other tank. The capacity of the tank for plant oil is 340 l while the smaller tank for mineral diesel fuel has an 80 l capacity. The capacity of both tanks is designated for 80 % functioning using plant oil which means that the engine is intended for all vehicles which most of the time function with high load of the engine. The engine is started with diesel fuel and heated to working temperature. It is automatically switched to oil when the oil is preheated to 70 °C by means of heated water from engine radiator or when output force of the engine reaches 25 % of maximally loaded engine for more than 30 seconds. When these conditions are not fulfilled the system automatically switches to mineral diesel fuel. Pipes and valve through which the plant oil flows are cleaned by mineral diesel fuel. This process lasts a few seconds and prevents entering plant oil in mineral diesel fuel. When the user puts out the engine he has to switch to mineral diesel fuel manually (there is an option of doing it automatically when the engine is put out). The user can always see on the terminal which fuel is currently used.

For stationary purpose MAN and some other producers developed systems with diesel engine and electric generator intended for cogeneration of electric and thermal energy from plant oils, waste edible oils and animal fat. Some big systems for cogeneration of electric and thermal energy already function in Belgium and Germany and new ones have been planned. For example, one system with nominal electric power of 85 MW and bigger systems are being prepared. MAN speaks in favour of using large diesel engines driven by plant oil which are used for driving of locomotives and ships. Beside MAN the firm SISU with their stationary applications is active in this sphere while Valmet tractors are being prepared to use SISU engines utilising plant oil. SISU is also studying the option of developing a "hybrid" engine that could utilise mineral diesel oil, biodiesel, plant oil and bioethanol. In Slovenia, the local firm Agromehanika offers tractors of 26 kW – 44 kW using pure plant oil and there are some tens of cars altered by individuals in order to be able to use plant oil.

3.7 WHAT SHOULD A DIESEL ENGINE RUNNING ON PLANT OIL BE LIKE

Following the example of Diesel some consumers and researchers tried to use plant oil directly in engines which were not adjusted to using this fuel. In older construction types of diesel engines, especially those with indirect injection of fuel (engines with IDI chambers – turbulence chambers) and high pressure in line piston pumps for fuel, no special problems were noticed in the beginning phases of use. However, after a longer use of such motors greater problems became evident. The results of investigation have shown that even the simplest and robust construction of the engines mentioned broke down some time after 500 hours of work. The problems which were observed were the following: plugging of fuel filter, occurrence of plaques in combustion chamber and in high pressure injection nozzles, damaged piston rings, etc. The question arises why did it come to that? The answer may be found in the construction of the current diesel engines and in fuel. Development of modern diesel engines was logically directed towards these kinds of fuels due to excellent availability of mineral diesel fuel. Plant oils are characterised by similar combustion to diesel fuel but their viscosity is too high for modern high pressure pumps for fuel and other elements in the fuel supply system. High viscosity causes plugging of fuel pipes, filter and high pressure injection nozzles. Investigations have shown that high viscosity results in incomplete atomisation (dispersal of fuel drops) of plant oil resulting in the prevention of complete combustion of larger fuel drops and production of carbon plaques. Consequently, plant oils can not be used directly in diesel engines. The following three methods were developed to reduce viscosity: transesterification of oil (commercial name: biodiesel), mixing of oil with mineral diesel fuel, and heating. As the first two methods are more demanding, the last one has proved to be the most adequate. Beside all the facts mentioned above, investigations have shown that plant oil had further delay of the beginning of combustion and slower combustion, especially in lower load of engines which results in later combustion and later expansion stroke of engine (adjustment of fuel injecting time leads towards the best solution of these problems).

3.8 SYSTEM FOR USING PLANT OIL AS FUEL FOR TESTED DIESEL ENGINES

3.8.1 One tank system

With the one-tank system the engine is modified to be driven exclusively by plant oil. In this case an electric pump should be built in. The main fuel filter is heated by means of heat exchanger which uses hot water from engine radiator. An important part of this system is electric heating of high pressure injection nozzles for fuel. This assures an optimum atomisation of fuel and lubrication of nozzle in high pressure injection nozzles for fuel independent on engine temperature.

3.8.2 Two tank system

With two-tank fuel system for starting and before stopping the engine, mineral diesel oil (instead of mineral diesel oil biodiesel may be used) is used. An additional fuel tank containing a small quantity of mineral diesel oil is added to the fuel supply system. Beside that, an additional electric fuel pump, electric fuel heater and electrically heated filter for rough filtering of fuel was built in. The engine is started by means of mineral diesel fuel. When the water in the engine radiator is heated to the temperature of approximately 60 °C, the thermostat switches on the electric fuel pump and fuel heater. Fuel coming from tank to high pressure fuel pump is heated in an electric heater to the temperature of 75 – 90 °C. The great advantage of this system is the fact that there are no problems with starting the engine during the period of low winter temperatures and, in case of plant oil shortage we can still use mineral diesel oil. The system is similar to that of driving a vehicle by liquid gas oil in which two fuels, gasoline and gas, are used (Bi-Fuel System). Additional diesel fuel tank in cars is simple to build in on the spot of spare tire (toroidal tank made of PE plastic or metal material), i.e. in the boot. With commercial vehicles, working machines, tractors, etc., it is not too difficult to build in an additional fuel tank due to larger space that these vehicles have at their disposal. Additional tanks for these vehicles can be obtained in different forms and capacities and they are made of PE plastic, stainless steel or aluminum (depending on manufacturer).

3.8.3 Functioning of the system used on test engines

To start the engine requires mineral diesel fuel or biodiesel contained in a small auxiliary fuel tank. After the engine reaches the proper working temperature, the electromagnetic valve switches the fuel supply from auxiliary tank to that from the main tank which contains pure plant oil. The latter passes through a special filter unit in which it is additionally purified and a heating unit in which it is additionally heated to reach the working temperature of (temperature at which the viscosity of pure plant oil approximately suits the viscosity of mineral diesel fuel). Heating of fuel reduces its viscosity and prevents the possibility of damaging the high pressure pump (stronger friction between working elements of the pump at very viscose oil and consequently higher working efforts), high pressure injection nozzles and piston rings due to incomplete combustion which would occur at high viscosity fuel. Steering of the process is fully automatic (electronic control unit) in order to relieve the user completely of the concern about the proper engine working.

Figure 1: Tractor AGT 835 transformed to using pure plant oil, equipped with three cylinder water cooled diesel engine with direct injection of fuel, engine capacity of 1551 cm^3, develops power of 26,4 kW.

The engine of the tractor AGT 835 (also the other engines were modified in the same way) has been modified for the use of 100 % plant oil with two-tank fuel system. To start the engine, mineral diesel oil (biodiesel may also be used – a better variant for the environment) placed in a small auxiliary fuel tank is used. When the tractor engine is heated to regular working temperature, the electromagnetic valve switches the fuel supply from auxiliary tank to main tank with plant oil. The latter comes through a special filter on which it is additionally heated and cleaned. Oil from filter comes through heating device on which it is additionally heated to working temperature between 75 to 95 °C (temperature at which the viscosity of plant oil approximately corresponds that of mineral diesel oil). Heating of fuel reduces its viscosity and prevents eventual damage of high pressure pump for fuel injection (higher friction between working elements of pump at very viscous oil and consequently higher working resistance) and high pressure injection nozzles and piston rings due to incomplete combustion which would occur at high viscosity fuel (plant oil). The plant oil supply in the engine is fully automated (the control is performed by electronic control unit) so that the user has not to be concerned about the proper use of the engine. Starting the engine does not require any special activities, but before stopping it requires manual switching to mineral diesel oil so that the engine is ready to restart using mineral diesel fuel.

Figure 2: On the upper side of AGT 835 tractor engine two tanks are built in: the left smaller tank contains mineral diesel oil and the right larger tank contains plant oil

Figure 3: Original engine on tractor AGT 835 before conversion to pure plant oil

Figure 4: Engine on tractor AGT 835 after conversion to pure plant oil. On the left side of the engine is an electromagnetic valve which channels the fuel from mineral diesel tank or from pure plant oil tank; on the right side there is an electric heater which heats the plant oil to maximum value adjusted by electronic thermostat on the instrument board of the tractor

Figure 5: A detail of electric heater of fuel; in the heater the plant oil is heated to 80 – 95 °C so that the oil viscosity corresponds approximately that of mineral diesel oil

Figure 6: On the left side of control panel is electronic thermometer and on the right side is switch for selection of mineral diesel fuel use or pure plant oil use

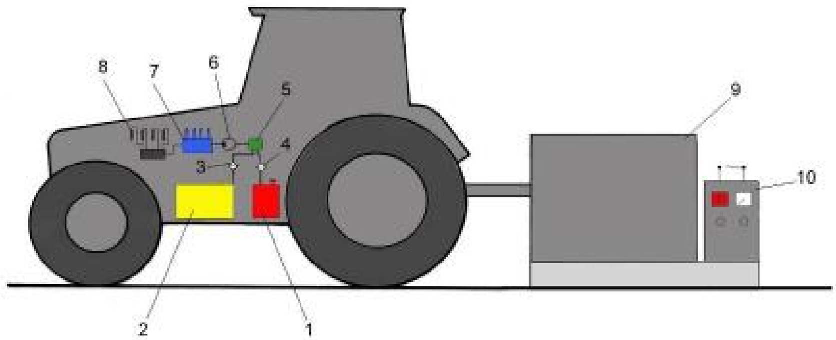


Figure 7: Conversion of engines on two tank system, same system was used on all three tested vehicles (off-road car Land Rover Defender and two tractors AGT 835 and Fendt Favorit), 1 - fuel tank for mineral diesel fuel D 2, 2 - fuel tank for pure plant oil 100 %, 3 - fuel filter, 4 - fuel filter, 5 - electromagnetic valve (three way), 6 - fuel pump (low pressure), 7 - heating device with electronic control unit (electrical system 12 V), 8 - injection nozzles with high pressure fuel pump, 9 - brake with dynamometer or electrical generator (both for different load simulation), 10 - main control unit

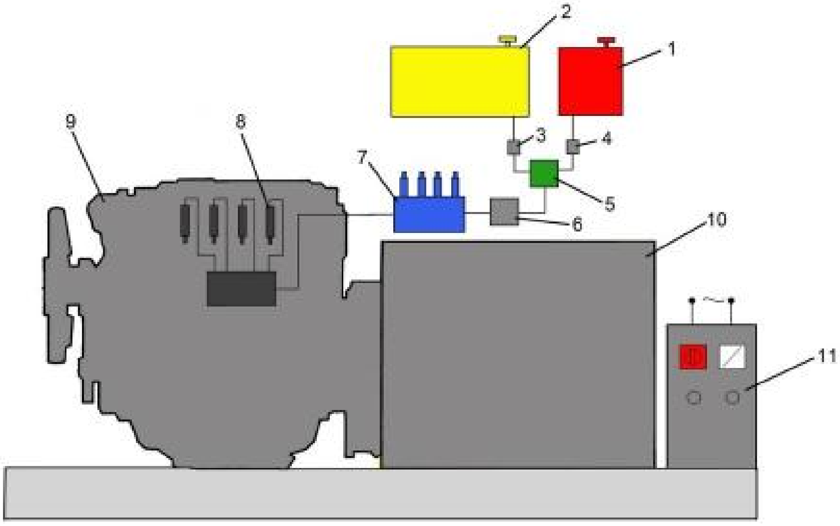


Figure 8: Conversion of engine on two tank system on laboratory diesel engine Lombardini with power of 25.7 kW, 1 - fuel tank for mineral diesel fuel D 2, 2 - fuel tank for pure plant oil 100 %, 3 - fuel filter, 4 - fuel filter, 5 - electromagnetic valve (three way), 6 - fuel pump (low pressure), 7 - heating device with electronic control unit (electrical system 12 V), 8 - injection nozzles with high pressure fuel pump, 9 - diesel engine, 10 – brake with dynamometer or electrical generator (both for different load simulation), 11 - main control unit

Figure 9: Conversion of engine on two tank system on vehicle Defender 110, Land Rover, on the left side of the engine is an electromagnetic valve which channels the fuel from mineral diesel tank or from pure plant oil tank to the electrical heating device for lowering viscosity of pure plant oil

4. FUEL CONSUMPTION

4.1 Fuel quality

Fuel quality of pure plant oil used on all engines was controlled. For fuel quality set of most important indicators was estimated. Indicators are: heating value (higher value, Mj/kg), phosphorous content (mg/kg), Iodine number (mg/kg), water content (mg/kg), density (g/l) and kinematic viscosity (Pa s). Phosphorous in combination with water forms phosphoric acid. It influence on shorter life cycle of engine with destroying metallic parts of engine. Iodine number is a measure of total unsaturation within a mixture of fatty materials, regardless of the relative shares of mono-, di-, tri- and polyunsaturated compounds. It is expressed in grams of iodine which react with 100 g of respective sample. Iodine number is limited to ≤ 120 g I^2/100 g in the EU. Fuels with high iodine number tend to polymerize and form deposits on injector nozzles, piston rings and piston ring grooves when they are heated. Highly unsaturated compounds have also been linked with decreased oxidation stability, causing the formation of various degradation products. Researches found that Iodine value has been in correlation with viscosity and cetane number, which both decrease with increasing degree of unsaturation. Viscosity is a measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress. Pure plant oil has viscosity ten to twenty times higher than the viscosity of fossil diesel fuel. This leads to poor fuel atomization and consequently in incomplete combustion. High flash point of pure plant oil and tendency for thermal or oxidative polymerization influences on formation of deposits on the injector nozzles. Dilution and degradation of engine oil and sticking of piston rings also occurs. For all indicated values recommended standard for pure plant oil was used. All controlled values (for indicators) in pure plant oil used for our experiments were bellow limits in mentioned standard. Pure plant oil was analyzed in chemical laboratory Petrol.

Table 2: Set of indicators for fuel - pure plant oil 100 % from rapeseed

Density at 15˚C (kg/m^3)	Kinematic viscosity at 40˚ C (mm^2/s)	Heating value (J/g) higher	Water content (mg/kg)	Flash point (˚ C)	Phosphorous content WD-XRF (mg/kg)	Look like
921,0	34,570	39068	140	> 240	< 10	clear, light yellow

In table is example of different values for pure plant oil 100 % (phosphorous content bellow 10 ppm) used in testing of diesel engines.

Table 3: Used testing methods for pure plant oil and limited values

Characteristic	Testing method	Limit values
Density at 15˚C (kg/m^3)	SIST EN ISO 12185	860 – 900
Kinematic viscosity at 40˚ C	SIST EN ISO 3104	3,5 – 5,0
Heating value (J/g) higher	mod. DIN 51900	37000 - 41000
Water content (mg/kg)	SIST EN ISO 12937	max. 500
Flash point (˚ C)	SIST EN ISO 2719	> 101
Phosphorous content (mg/kg)	PML 07.30	≤ 10
Look	PML 07.09	clear

Fuel consumption of all included engines was established through measurement of fuel volume consumed in time unit for tractor and laboratory engine and at distance unit for off-road vehicle. Average consumption was calculated from total volume of consumed fuel and total time or total number of kilometers covered during measuring period. Fuel consumption of laboratory engine was calculated daily.

Tractor FAVORIT 612, FENDT had the average consumption 7.38 l/h. At 2000 rpm of engine main shaft one working hour is the same as time of one hour that mean that one working hour represents 120 000 revolutions of main engine shaft. Tractor was used for different working operations: primary and secondary soil tillage with plow and rotary tiller, for mowing and hay making, silage maize harvesting and for transport. Off-road car Defender 110 Land Rover had average consumption 12,78 l/100km. Average daily number of kilometers covered was 43. There were some longer drives over 250 km distances, where car used pure plant oil. For laboratory stationary engine Lombardini LWD 1503 daily consumption was calculated for each single type of fuel burned up during time unit and at one working hour. Engine was running at about 1920 rpm and producing about 12 kW of power set by hydraulic brake. Power was calculated from measured torque with torque transducer T 30 FN Hottinger Baldwin and angular velocity measured with inductive sensor on torque transducer T 30 FN Hottinger Baldwin. From daily consumptions average values were calculated and presented on table below. Tractor AGT 835 worked with pure plant oil in transport and light field and livestock operation activities.

Stationary laboratory engine Lombardini LWD 1503 is the same like engine on tractor AGT 835. For this reason main measurements were made in controlled laboratory conditions on stationary laboratory engine. Some activities and measurements will be made in real conditions with tractor AGT 835. Average consumptions for each type of fuel were calculated from daily measured values during whole testing period and are presented on table below.

Table 4: Average consumptions for different fuels and relative difference to diesel fuel consumption for whole measuring period on stationary laboratory engine Lombardini LWD 1503.

Fuel	Diesel fuel	Biodiesel	Pure plant oil
Average consumption [l/h]	1,30	1,21	1,38
Difference to diesel [%]		-7,36	5,59
Average consumption [l/wh]	1,37	1,27	1,45
Difference to diesel [%]		-6,81	6,18

If we compare these values with average consumption from first measuring period we can realize that consumptions of all three fuel origins decrease.

Table 5: Average consumption for different fuel types in first measuring period stationary laboratory engine Lombardini LWD 1503.

Fuel	Diesel fuel	Biodiesel	Pure plant oil
Average consumption [l/h]	1,38	1,30	1,47
Average consumption [l/wh]	1,44	1,35	1,53

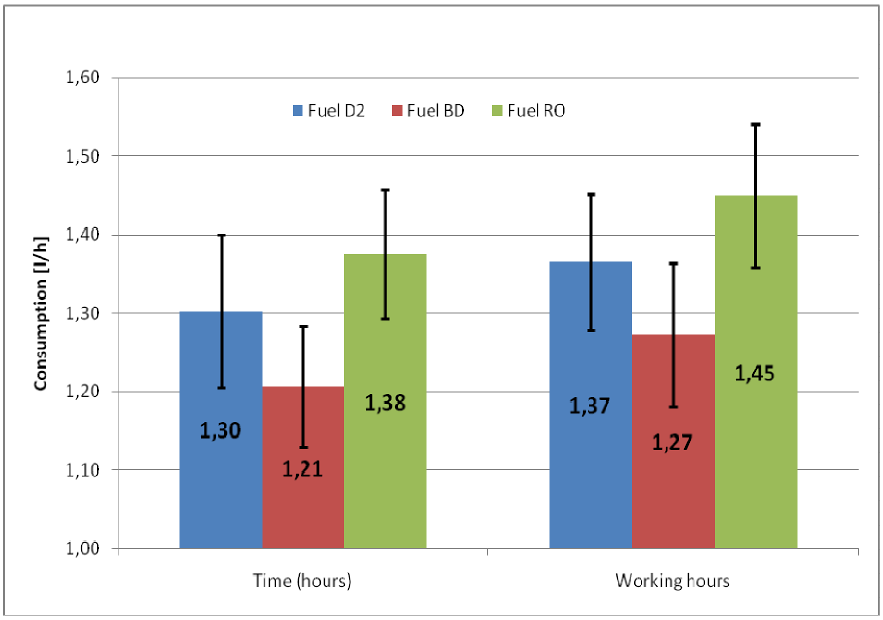


Figure 10: Fuel consumption of laboratory engine Lombardini LWD 1503 for three different types of fuel (mineral diesel fuel, pure plant oil and biodiesel) with 95% confidence limits for whole measuring time.

Biodiesel proves the lowest consumption and plant oil the highest like in the first measuring period. In spite of higher number of measurements the variability of fuel consumption is too high that differences could be accepted as significant. The conclusion from last report, that consumption is not dependent on type of fuel but on delivery rate of fuel injection pump as set for single cylinder injector, could be confirmed with these results.

4.2 EXHAUST EMISSIONS FROM ENGINES

Based on measurements of exhaust gas on modified engines of vehicles and laboratory engine the target was to determine how the type of used fuel influenced on emissions of gases. Particulate emissions and single gas levels measurements were performed at low speed - idle and at medium and high engine speeds. Particulate emissions have also been measured at the acceleration from idle to maximum engine speed at unload engines.

The major part of combustion engine exhaust gas consists of the non toxic components, nitrogen, carbon dioxide and water. However, about 1,4 % of gasoline engine exhaust and 0,2 % of diesel engine exhaust are composed of more or less harmful substances. The maximum amounts of certain pollutants are regulated by national authorities. In the European Union and USA these limited emissions are: CO, HC, NO_x and particulate matter (Mitelbach 2004).

4.2.1 Tractor AGT 835, Agromehanika

Measurements were made with low (idle), medium and high speed of engine (rpm). The results with low (idle) speed of engine shows that O_2 is slightly higher for mineral diesel fuel in comparison with pure plant oil, HC is also lower for mineral diesel fuel.

CO_2 and CO are also slightly lower for mineral diesel fuel. At medium speed of engine O_2 is slightly lower for mineral diesel fuel in comparison with pure plant oil, HC is also lower for mineral diesel fuel. CO_2 and CO are also slightly lower for mineral diesel fuel. At high speed of engine O_2 is slightly higher for mineral diesel fuel in comparison with pure plant oil, HC is also lower for mineral diesel fuel. CO_2 is also slightly lower for mineral diesel fuel and CO is slightly lower for pure plant oil.

Continuous measurement of the particulate emissions of engine at non changed conditions (AGT 835)

Engine speed [rpm]	T_{oil} [°C]	T_{ex} [°C]	T_{vz} [°C]	Absorption coefficient [min^{-1}]
Fuel: diesel				
Low	84	84	15	0,00
Medium	86	115	15	0,02
High	91	171	15	0,15
Fuel : PPO 100 %				
Low	75	95	11	0,17
Medium	76	119	11	0,05
High	83	180	11	0,10

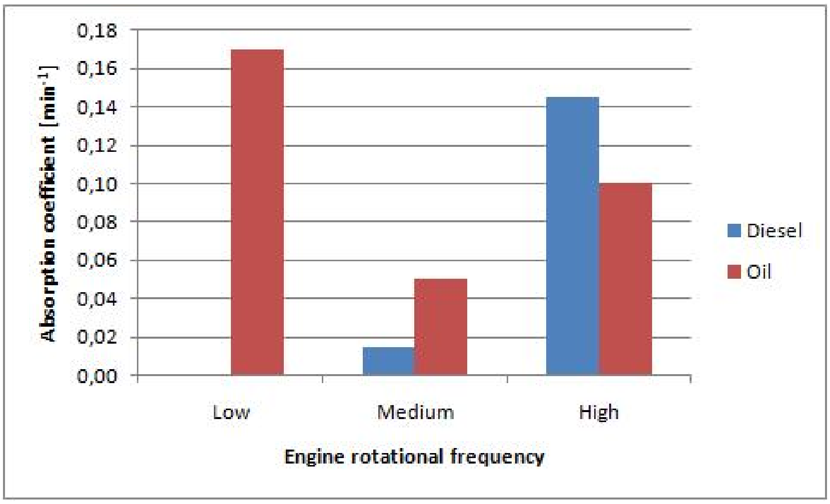


Figure 11: Absorption coefficient for continuous measurement of the unloaded tractor engine AGT 835

Particulate emissions at idle running engine are the highest with the pure plant oil. For diesel fuel is below the detection limit. With increasing engine speed at the use of diesel fuel particulate emissions increases and at the maximum speed they are greater than with pure plant oil.

Measurement of particulate emissions at acceleration of tractor engine AGT 835

	Idle [rpm]	Max. speed [rpm]	Oil temperature [°C]	Absorption coefficient [min^{-1}]
Diesel	850	2800	79	0,41
Pure plant oil	828	2750	86	0,46

Particulate emissions at the acceleration of engine are slightly higher for pure plant oils than when using mineral diesel fuel.

Gas values of tractor engine AGT 835

Engine speed [rpm]		T_{oil} [°C]	CO [%]	CO_2 [%]	HC [ppm]	O_2 [%]
Low	Diesel	74	0,007	2,39	6	17,63
	Oil	79	0,054	2,93	17	17,02
Medium	Diesel	77	0,014	2,38	6	17,57
	Oil	80	0,038	2,60	6	17,46
High	Diesel	89	0,024	3,30	9	16,28
	Oil	86	0,017	3,62	6	16,07

It should be noted that the values of gases in using of pure plant oil are higher than in using of mineral diesel fuel, except for O_2 value where the reverse is true.

4.2.2 Tractor FAVORIT 612, FENDT

Measurements were made with low (idle), medium and high speed of engine (rpm). The results with low (idle) speed of engine shows that O_2 is slightly higher for mineral diesel fuel in comparison with pure plant oil, HC is also slightly higher for mineral diesel fuel. CO_2 and CO are also slightly lower for mineral diesel fuel. At medium speed of engine O_2 is slightly higher for mineral diesel fuel in comparison with pure plant oil, HC is also lower for mineral diesel fuel. CO_2 and CO are also slightly lower for mineral diesel fuel. At high speed of engine O_2 is slightly higher for mineral diesel fuel in comparison with pure plant oil, HC is higher for mineral diesel fuel. CO_2 and CO are slightly lower for mineral diesel oil.

Gas values of tractor engine FAVORIT 612, Fendt

Engine speed (rpm)		T_{oil} [°C]	CO [%]	CO_2 [%]	HC [ppm]	O_2 [%]
Low	Diesel	79	0,040	1,47	21	18,75
	Oil	77	0,103	1,57	30	18,56
Medium	Diesel	78	0,029	1,92	26	18,21
	Oil	79	0,114	2,06	37	18,00
High	Diesel	82	0,026	2,78	35	16,99
	Oil	84	0,084	2,88	33	16,99

It should be noted that the values of gases at using of pure plant oil are higher than when using diesel fuel.

Continuous measurement of the particulate emissions on engine at non changed conditions (FAVORIT 612 Fendt)

Engine speed [rpm]	T_{oil} [°C]	T_{exh} [°C]	T_{vz} [°C]	Absorption coefficient [min^{-1}]
Fuel: Diesel				
Low	79	108	19	0,00
Medium	78	131	19	0,00
High	82	206	19	0,19
Fuel: PPO 100 %				
Low	77	103	20	0,09
Medium	77	127	20	0,08
High	82	202	20	0,28

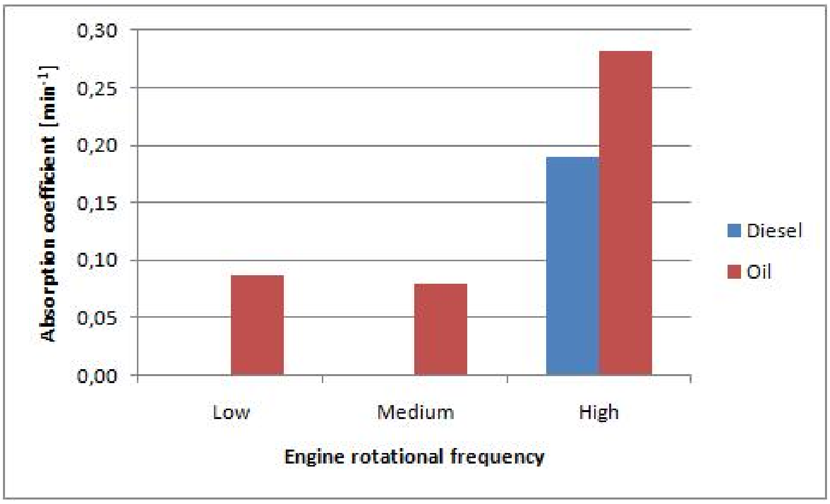


Figure 12: Absorption coefficient for continuous measurement of the unloaded engine on tractor FAVORIT 612, Fendt

Particulate emissions at idle and medium speeds are lower at use of pure plant oil, the highest value is at the highest speeds. Using diesel fuel at idle and medium engine speeds is below the detection limit. At high speeds particulate emissions increased, but less than with pure plant oil.

Measurement of particulate emissions at acceleration of tractor engine FAVORIT 612, Fendt

	Idle [rpm]	Max. speed [rpm]	Oil temp [°C]	Absorption coefficient [min^{-1}]
Diesel	750	2500	80	1,19
Oil	750	2500	78	4,10

Particulate emissions at acceleration of engine using pure plant oil are greater than when using diesel fuel. This is because direct fuel injection and turbo charger ineffectiveness at lower engine speeds, resulting in incomplete combustion and consequently excessive smoke especially at the use of pure plant oil.

4.2.3 Off-road car Defender 110 Land Rover

Measurements were made with low (idle), medium and high speed of engine (rpm). The results with low (idle) speed of engine shows that O_2 is slightly higher for mineral diesel fuel in comparison with pure plant oil, HC is same for mineral diesel fuel and pure plant oil. CO_2 and CO are also slightly lower for mineral diesel fuel. At medium speed of engine O_2 is slightly lower for mineral diesel fuel in comparison with pure plant oil, HC is higher for mineral diesel fuel. CO_2 and CO are slightly lower for mineral diesel fuel. At high speed of engine O_2 is slightly higher for mineral diesel fuel in comparison with pure plant oil, HC is higher for mineral diesel fuel. CO_2 is slightly lower for mineral diesel oil and CO is slightly higher for mineral diesel oil.

The vehicle has a water-cooled four-cylinder naturally aspirated with pre chamber in the cylinder head. Nominal power of engine is 51 kW.

Continuous measurement of the particulate emissions on engine at non changed conditions (Defender 110 Land Rover)

Speed[rpm]	T_{oil} [°C]	T_{exh} [°C]	T_{vz} [°C]	Absorption coefficient [min^{-1}]
Fuel: Diesel				
Low	79	66	34	0,06
Medium	78	106	34	0,03
High	82	176	34	0,14
Fuel: PPO 100 %				
Low	79	74	32	0,30
Medium	85	92	32	0,08
High	94	166	32	0,03

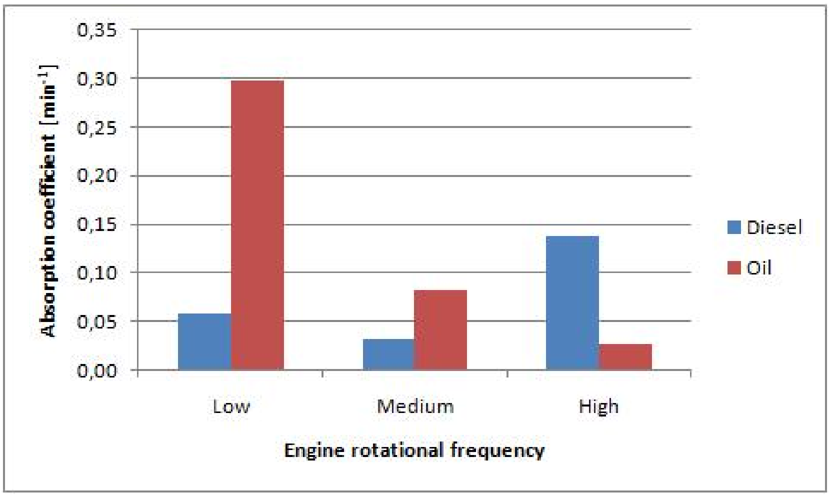


Figure 13: Absorption coefficient for continuous measurement of the unloaded engine of Defender 110 Land Rover

Particulate emission values at idle and at medium speeds when using pure plant oil are higher than when using diesel fuel. For maximum speed of engine particulate emission values with diesel fuel are higher than when using pure plant oil.

Measurement of particulate emissions at acceleration of engine of Defender 110 Land Rover

	Idle [rpm]	Max. speed [rpm]	Oil temp. [°C]	Absorption coefficient [min^{-1}]
Diesel	740	4000	95	2,74
Oil	740	4000	91	1,6

Particulate emissions at acceleration of engine using pure plant oils are lower than with diesel fuel.

Gas values for Defender 110 Land Rover

Engine speed (rpm)		T_{oil} [°C]	CO [%]	CO_2 [%]	HC [ppm]	O_2 [%]
Low	Diesel	83	0,068	2,37	21	17,58
	Oil	91	0,131	2,87	38	16,97
Medium	Diesel	89	0,094	2,53	29	17,33
	Oil	89	0,159	2,45	51	17,57
High	Diesel	101	0,028	3,97	15	15,27
	Oil	99	0,031	4,08	14	15,48

It should be noted that nearly all the values of gases at using of pure plant oil are a little higher than when using diesel fuel.

4.2.4 Laboratory engine Lombardini LWD 1503

Water cooled three cylinder naturally aspirated engine with pre chamber in the cylinder head. Nominal power of engine is 26 kW. The engine uses three fuels at the same time. The first cylinder uses pure plant oil (100 %), second cylinder biodiesel and third cylinder diesel fuel.

Measurements were made with medium and high speed of engine (rpm). The results with medium speed of engine shows that O_2 is slightly higher for pure plant oil in comparison with mineral diesel fuel and biodiesel, HC is higher for pure plant oil in comparison with mineral diesel fuel and biodiesel. CO_2 and CO are also slightly lower for mineral diesel fuel and biodiesel. At high speed of engine O_2 is slightly lower for biodiesel in comparision with mineral diesel fuel and pure plant oil, HC is higher for pure plant oil. CO_2 is slightly lower for pure plant oil in comparison with mineral diesel fuel and bio-diesel. CO is slightly lower for mineral diesel oil in comparison with biodiesel and pure plant oil.

Continuous measurement of the particulate emissions on engine at non changed conditions (Lombardini LWD 1503)

Speed [rpm]	T_{oil} [°C]	T_{exh} [°C]	T_{vz} [°C]	Absorption coefficient [min^{-1}]
Fuel: Diesel				
Low	84	94	26	0,00
High	84	102	30	0,02
Fuel: PPO 100 %				
Low	80	64	26	0,00
High	82	91	30	0,00

Fuel: Biodiesel				
Low	83	79	26	0,01
High	84	94	30	0,02

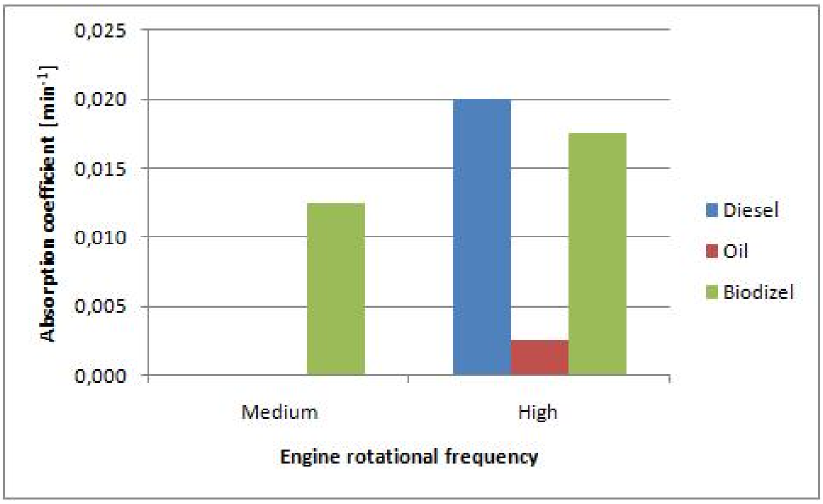


Figure 14: Absorption coefficient for continuous measurement of the unloaded engine of Lombardini LWD 1503

Particulate emissions at low speeds of engine when using pure plant oil and diesel fuel are below the detection limit; only at using biodiesel the value of absorption coefficient is 0.013. At high speeds, the particulate emissions with diesel fuel are the highest and at use of pure plant oil are the lowest.

Measurement of particulate emissions at acceleration of engine of Lombardini LWD 1503

	Idle [o/min]	Max. speed [rpm]	Oil temp. [°C]	Absorption coefficient [min^{-1}]
Diesel	1312	2566	84	0,79
PPO 100 %	1298	2590	85	0,31
Biodiesel	1284	2500	85	0,40

Particulate emission values are at idle and at medium speeds when using pure plant oil are greater than when using diesel fuel. For maximum speed particulate emission values with diesel fuel are higher than when using pure plant oil.

Engine gas levels for Lombardini LWD 1503

Engine speed (rpm)		T_{olja} [°C]	CO [%]	CO_2 [%]	HC [ppm]	O_2 [%]
Low	Diesel	82	0,011	3,12	10	16,41
	Oil	82	0,031	3,59	25	15,85
	Biodesel	82	0,013	2,46	18	17,45
High	Diesel	103	0,019	3,03	13	16,63
	Oil	98	0,029	4,49	19	14,58
	Biodesel	100	0,019	3,81	14	15,44

5. MOTOR OIL QUALITY ON LABORATORY ENGINE AND ENGINES OF TRACTORS

Samples of the engine lubricating oil were taken from all four diesel engines (laboratory engine and engines on three vehicles) at regular sampling intervals. Engine oil was SAE 15 W – 40 (producer Texaco) for all diesel engines.

For engine oil quality set of most important indicators was estimated. Indicators are: base number (mg KOH/g), parts of wear metals from engine - Al, Cr, Cu, Fe, Pb, Sn (mg/kg), nonmetal parts - Si (mg/kg), viscosity index and water content (mg/kg). The motor oil contains a lot of valuable information about oil and state of engine.

Base number

Oil base number measures its alkaline reserve or ability to neutralize degradation acids. Decrease in base number typically accomplied by an increase in oxidation, nitration and viscosity.

Viscosity

Viscosity is defined as a measure of a fluids resistance to flow. The standard measure of this property for engine oils is termed “kinematic viscosity”. Kinematic viscosity is based on ability of oil to flow under the influence of gravity through a capillary tube. The test for kinematic viscosity is defined by standard ASTMD 0445.

Viscosity can increase in case of accumulation of combustion by products (mainly soot) which can thicken the oil. Heat, water and engine coolant (glycol) can cause oxidation of oil. Viscosity can decrease with fuel dilution. Another possible reason for viscosity decrease is shearing of the long chain polymer molecules that comprise the viscosity improver additives. In such case the oil can no longer maintain performance at higher temperatures and migrates toward the lower viscosity of the base stock mineral oil. In either case fuel dilution or shearing the oil can thin down to the point it can no longer maintain an adequate oil film at operating temperatures.

Wear Metals (Copper, Iron, Chromium, Aluminium, Lead, Tin)

Wear metals indicate wear on particular components in a compartment. The particles reported in parts per million (PPM) indicates a wear problem on a microscopic level before the problem can be detected by conventional means. Wear problem is determined not only by maximum limits for each metal, but more importantly, by a relative increase or trend in one or more of these metals.

Limit levels and warning levels serve as indicators of the amounts of foreign particles found in used engine oil that are still tolerable or when compared with fresh oil indicate when the altered lubricant must be changed. It is not easy to specify warning levels. Hardly any engine or equipment producer defines limit values for used engine oils. This is because the operating conditions and times are too specific and the origins of the foreign particles found in the oil are too diverse. When warning and limit levels are used for the diagnosis of specific oil specimen the interactions between the values and other criteria should also be taken into account. A variety of factors influence, like engine producer, engine type, type of oil used, oil volume, the service life of oil etc. The operating conditions can also vary from one situation to the next. The engines of tractors, construction machines and other working machines operate under different conditions than engines of vehicles which travel on long distances with constant speed (trucks on highways etc.).

Iron

Origin of iron in the motor oil specimen is from cylinder block, cylinder head, valves, rocker arm shaft, piston pins, roller bearings (with chromium), timing wheels and timing chains and oil pump. Rare, residues can be from ferrocene which is fuel additive for soot reduction.

Chromium

Origin from chromium is from piston rings, crankshaft bearings, piston pins, exhaust valves, gaskets, guide bushes, chrome-plated parts. Aluminium and chromium are usually found in combination with

Silicium in engines. Dust causes wear of most Aluminium pistons, piston rings with chromium and engine cylinder (iron) wear.

Copper

As wear metal copper can be from oil pumps, connecting road bearings, piston pin bearings, rocker arm shaft bearings, bronze worm gears. Cooper is also result from corrosion of oil coolers, piping and seals.

Lead

Usually comes with tin and copper. Origin in oil specimen is from rod bearings, nearly all running surfaces of plain bearings and soldered joints in combination with tin.

Aluminium

Primarily origin is from pistons, oil coolers, turbocharger, guide bushes, plain bearings, cylinder blocks (for aluminium blocks), and dust containing bauxite (aluminum oxide).

Tin

Origin from tin is from running surfaces of connecting – rod bearings, rocker arms, shaft and pin bearings, solder (consisting of lead and tin) in soldered radiator joints. It is also constituent of some synthetic base oils. Often is together with lead (Babbit bearings) or copper.

Silicon

Silicon is non metal particle. Sand, dirt, dust or similar type of abrasive ingested into the system. May also be indicative of an anti-foam additive. Silicone particles can be from seal/gaskets or engine building materials. Silicon normal level is 6 – 12 %. Anything above 22 could effect anti-foam package. Note: anti-foam level is a delicate balance (more or less is not better) it is possible high dirt or "silicon" levels can throw anti-foam balance.

Table 6: Wear metals contents in PPM for engine oil, upper warning level (Typical limit values for motor oils from diesel engines – stationary or non stationary, Wear metals, contaminants and additives

Iron	80 -180
Copper	25 – 60
Chromium	4 – 28
Aluminium	12 – 55
Lead	10 – 30
Tin	12 – 24

Table 7: Wear metals and silicon contents in PPM for engine oil (Synmax University, www.synmaxperformancelubricants.com)

Wear Metal	Normal	Higher	Severe	Extra Severe
Iron	100	100 - 250	250 - 400	› 400
Copper	40	40 – 100	100 - 200	› 200
Chromium	40	40 – 100	100 - 200	› 200
Aluminium	40	40 – 100	100 - 200	› 200
Lead	50	50 – 100	100 - 200	› 200
Silicon	20	20 – 50	50 - 100	› 100

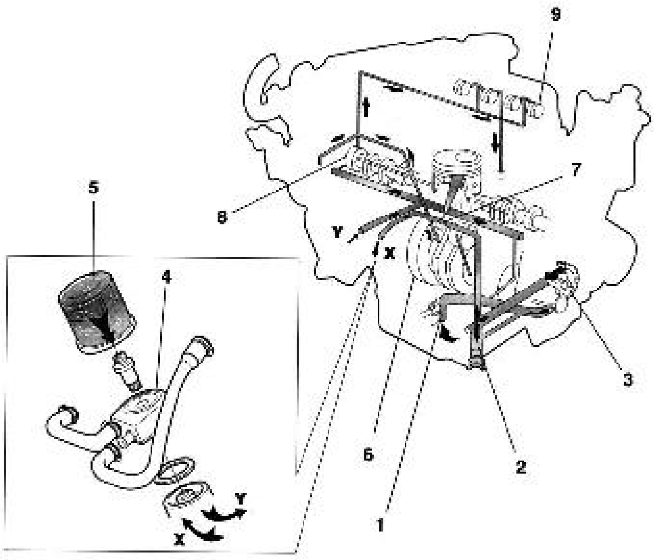
Table 8: Wear metals and silicon contents in PPM for engine oil, Deutz limit; Deutz oil laboratory (Knuth and Winkler 2009, Implementation of 500 h Engine Test cycle and Field Testing of Deutz Common –Rail Engines in Heavy-Duty EURO IV Truck Applications for Release of Biodiesel)

Iron	150
Copper	20
Chromium	20
Aluminium	25
Lead	30
Silicon	20

Table 9: Used testing methods for engine oils and limited values (Petrol laboratory)

Number of working hours	**Unit**	**Testing method**	**Limit values**
Base number	mg KOH/g	SIST ISO 3771	25 – 35 %
Viscosity index		SIST ISO 2909	
IR spectrum		DIN 51451	
Kinematic viscosity 100 ºC	mm^2/s	Mod. ASTM D 445	15-20
Kinematic viscosity 40 ºC	mm^2/s	Mod. ASTM D 445	15-20
Metals WD-XRF			
Aluminium (Al)	mg/kg	PML.07.16	20-40
Chromium (Cr)	mg/kg	PML.07.16	15-30
Copper (Cu)	mg/kg	PML.07.16	30-50
Iron (Fe)	mg/kg	PML.07.16	75-100
Lead (Pb)	mg/kg	PML.07.16	30-50
Tin (Sn)	mg/kg	PML.07.16	20-40
Non metals WD-XRF			
Silicon	mg/kg	PML.07.16	25-40
Water	mg/kg	Mod. ASTM D 6304	500 – 1000

The oil pump sends oil through engine filter. Engine oil from oil pan comes to filter element and from filter flows into the engine oil manifold. This oil then flows into different block oil passages to lubricate and cool different engine components and the return back in oil pan.



Lubrication on laboratory engine and engine of tractor AGT 835, 1- intake of oil, 2 – oil intake from oil pan on oil filter element and timing gears, 3 – timing gears, 4 – oil pump, 5 – filter element, 6 – crankshaft, 7 – piston cooling, 8 – camshaft, 9 - rocker arm shaft

5.1 Laboratory engine

Laboratory engine oil had higher iron and cooper amount of particles in period (from 222 to 607 working hours). Limits for cooper and iron were higher than permitted limits. Other metals were under recommended limits. Quantity of silicon was also higher in some periods (this is connected with contamination with casting residues in engine and dirt from outside air). Water was always bellow the limits for water content in engine oils. After every adding of new part of oil or complete exchange engine oil (disassembling and assembling of engine for control of deposits on cylinders, pistons and other parts of engine) content of copper and iron particles rapidly dropped to normal.

Cylinder, piston and piston rings were after openings and measurements in normal conditions (they were not replaced with new parts) because wear of mentioned parts was not higher than recommended for engines (manufacturer recommendations).

Kinematic viscosity at 40 °C or 100 °C measures a lubricant's resistance to flow (fluid thickness) at temperature and is considered an oil's most important physical property. Depending on lube grade, viscosity is tested at 40 and/or 100° C. Kinematic viscosity at 100 °C for motor oil SAE 15 W – 40 is between 12, 5 – 16, 3 mm^2 /s. All values for kinematic viscosity for samples of motor oils were normal (in accordance with low and high limit values for viscosity at 100 °C).

IR spectrum was also done. Conclusion from IR spectrum done was that in the every sample of engine oil on analysis was always some part of pure plant oil (unburned pure plant oil diluted in engine oil). But this was not bigger problem, because after every taking of sample of motor oil from engine, motor oil in engine was refreshed with added part of new – fresh motor oil.

Conclusions

Limit values (microscopic level) were exceeded in the case of laboratory engine for iron and cooper. This can be explained partly that laboratory engine was new at the start of tests. In starting of use new engines always is wear of some engine parts higher (cylinders, pistons etc.) because engine need time for run-in period. After every sampling interval, part of motor oil was taken and replaced with fresh oil (1,5 l). There is also possibility that metal particles (especially cooper and iron) were for longer period at oil pan, because oil was only partial refreshed when quantity taken for sampling was replaced with fresh oil. Only after opening the engine for estimating the condition of engine (cylinder, pistons, piston rings, nozzles etc.), motor oil pan was washed and oil completely exchanged with new.

Origin of iron in the motor oil specimen can be from different parts of engine like: cylinder block, valves, rocker arm shaft, piston pins, roller bearings (with chromium), timing wheels etc. Rare, residues can be from ferrocene which is fuel additive for soot reduction.

Some part of pure plant oil was also diluted in motor oil but this not influenced on higher content of wear metals in engine oil. Why dilution can be problem and how fuel (pure plant oil) was diluted. Quality of pure plant oil burning is lower in comparison with mineral diesel fuel because pure plant is not atomized in very small fuel droplets like mineral diesel fuel. Bigger droplets will not totally burn or time needed for its burning will be longer and small part of unburned fuel will dilute in engine oil. Biodiesel or pure plant dilute engine oil, diluted engine can influence on increased wear rates of engines. In fuel combustion all delivered fuel (pure plant oil or biodiesel) will not burn fully. Some fuel will pass between piston rings and cylinder wall to the crankcase where it dilutes or mixes with the engine oil for lubricating oil. In the case of mineral diesel fuel mixed with engine oil the heat in the crankcase will evaporate mineral diesel fuel. Biodiesel or pure plant oil will not evaporate easily. Engine oil diluted with biodiesel or pure plant oil will change viscosity to lower value and lubricity. In diluted engine oil also characteristics of anti wear additives in oil can change.

Dimensions of cylinders and pistons on laboratory engine and both tractors after every opening of engines were bellow limits for wear of engines. Cylinders and pistons were without damages (we do not need to replace pistons or rings etc.).

Solution for future use of engine oils

Changing intervals for engine oil can be halved in comparison with normal intervals for engine oils and quality of engine oil will not be critical.

Table 10: Engine oil analyses of laboratory engine Lombardini

PPO 2			Oil quality description/criteria				Working hours					Status*
Parameter	**Unit**	**Limit values**	**New**	**Normal**	**Serious**	**Alert**	**222,5**	**293**	**427**	**512**	**607**	
Basic number	mg KOH/g	(-) 25 – 35 % from initial value	10.5	6,8 - 10.5			11,3	12	10,2	11	11,5	S
Viscosity index		Significant change from initial value	137	137 – 150			168	175	163	148	146	S/A
IR spectrum		Typical (T)	T	T	N	N	T	T	T	T	T	T
Kinematic viscosity at 100 ºC	mm^2/s	(±) 15-20 % from initial value	15	12 - 15			15,48	15,04	15,3	15,17	14,9	N/S
Kinematic viscosity at 40 ºC	mm^2/s	(+) 15-20 % from initial value	100	100 - 120			98,02	90,62	99,47	107,5	106,3	N/S
Metals WD-XRF												
Aluminium (Al)	mg/kg	20-40		20-40	40-100	100-200	13	13	11	10	10	N
Chromium (Cr)	mg/kg	15-30		15-30	40-100	100-200	30	26	24	22	19	N
Copper (Cu)	mg/kg	30-50		30-50	40-100	100-200	81	55	106	128	127	S/A
Iron (Fe)	mg/kg	75-100		75-100	100-250	250-400	252	214	214	214	174	S/A
Lead (Pb)	mg/kg	30-50		30-50	50-100	100-200	22	18	15	15	17	N
Tin (Sn)	mg/kg	20-40		20-40			8	< 6	7	7	9	N
Non metals WD-XRF												
Silicon	mg/kg	25-40		25-40			158	108	69	52	37	S/A
Water	mg/kg	500 – 1000	<500	500 – 1000	>1000		60	< 30	160	120	70	N

Note: * - either: New/Normal/Serious/Alert/Severe according to the values. Severe values are higher than alert values.

** - Typical (T) or Non-typical (N) IR spectra determined for oil sample.

PPO 1 – pure plant oil with phosphorous content < 10 ppm, PPO 2 – pure plant oil with phosphorous content > 10 ppm

5.2 FENDT LSA 612

Limit values (microscopic level) metal and non metal particles in motor oils were exceeded in the case of tractor FENDT LSA 612 only once for silicon particles. In this case silicon was from the outside air.

Viscosity index was estimated. For new oil SAE 15 W – 40 viscosity index is 137 (Petrol laboratory values). In case of tractor FENDT LSA 612 this index was higher from initial value from 18,2 % up to 41,6 %.

Kinematic viscosity at 40 °C or 100 °C measures a lubricant's resistance to flow (fluid thickness) at temperature and is considered an oil's most important physical property. Depending on lube grade, viscosity is tested at 40 and/or 100° C. Kinematic viscosity at 100 °C for motor oil SAE 15 W – 40 is between 12, 5 – 16, 3 mm^2 /s. Petrol laboratory uses value for fresh oil SAE 15 W – 40 TD from 14 – 15 mm^2 /s. Values for used motor oils can be lower from mentioned values from 15 to 20 % (Petrol laboratory values), so in the one sample of motor oil estimated value was lower than recommended.

IR spectrum was also done. IR spectrum was typical (limit in this case is non tipical value of IR spectrum, Petrol laboratory). Also conclusion from IR spectrum was that in the every sample of engine oil on analysis, was always some part of pure plant oil (unburned pure plant oil diluted in engine oil). But this was not bigger problem, because after every taking of sample of motor oil from engine, motor oil in engine was refreshed with added part of new – fresh motor oil. Water was always bellow the limits for water content in engine oils.

Conclusions

In the case of particles in motor oil of diesel engine on tractor Fendt 612 from particles was only silicon in one sample of motor oil exceeded (status - alert). Basic number was serious lower in one case. Viscosity index was serious lower in two cases. Kinematic viscosity was lower than recommended value in one case (status – alert). In general motor oil was diluted with part of fuel (pure plant oil 100 %) but this not influenced on content of wear metals in engine oil. Why dilution can be problem and how fuel (pure plant oil) was diluted. Quality of pure plant oil burning is lower in comparison with mineral diesel fuel because pure plant is not atomized in very small fuel droplets like mineral diesel fuel. Bigger droplets will not totally burn or time needed for its burning will be longer and small part of unburned fuel will dilute in engine oil. In fuel combustion all delivered fuel (pure plant oil or biodiesel) will not burn fully. Some fuel will pass between piston rings and cylinder wall to the crankcase where it dilutes or mixes with the engine oil for lubricating oil. In the case of mineral diesel fuel mixed with engine oil the heat in the crankcase will evaporate mineral diesel fuel. Biodiesel or pure plant oil will not evaporate easily. Motor oil diluted with biodiesel or pure plant oil will change viscosity to lower value and lubricity. In diluted engine oil also characteristics of anti wear additives in oil can change.

Dimensions of cylinders and pistons on laboratory engine and both tractors after every opening of engines were bellow limits for wear of engines. Cylinders and pistons were without damages (we do not need to replace pistons or rings etc.).

Solution for future use of motor oils

Changing intervals for engine oil can be halved in comparison with normal intervals for engine oils and quality of engine oil will not be critical.

Table 11: Engine oil analyses of tractor Fendt 612 LSA

PPO 2			**Oil quality description/criteria**				**Working hours**				**Sta-tus**
Parameter	**Unit**	**Limit values**	**New**	**Nor-mal**	**Seri-ous**	**Alert**	**4602**	**4651**	**4758**	**4800**	
Basic number	mg KOH/g	(-) 25 – 35 % from initial value	10.5	6,8 - 10.5			4,4	11,8	10,8	6,4	N/A
Viscosity index		Signifi-cant change from initial value	137	137 – 150			194	170	174	172	S/A
IR spec-trum		Typical (T)	T	T	N	N	T	T	T	T	T
Kinematic viscosity at 100 ºC	mm^2/s	(-) 15-20 % from initial value	15	12 - 15			10,38	11,90	11,28	12,43	S
Kinematic viscosity at 40 ºC	mm^2/s	(+) 15-20 % from initial value	100	100 - 120			51,95	69,04	63	72,03	S/A
Metals WD-XRF											
Alumini-um (Al)	mg/kg	20-40		20-40	40-100	100-200	< 6	< 6	< 6	17	N
Chromium (Cr)	mg/kg	15-30		15-30	40-100	100-200	< 3	< 3	< 3	< 3	N
Copper (Cu)	mg/kg	30-50		30-50	40-100	100-200	4	< 3	< 3	< 3	N
Iron (Fe)	mg/kg	75-100		75-100	100-250	250-400	10	7	15	18	N
Lead (Pb)	mg/kg	30-50		30-50	50-100	100-200	3	< 3	< 3	< 3	N
Tin (Sn)	mg/kg	20-40		20-40			< 6	< 6	< 6	< 6	N
Non met-als WD-XRF											
Silicon	mg/kg	25-40		25-40			8	< 6	12	66	N/S
Water	mg/kg	500 – 1000	<500	500 – 1000	>1000		340	260	150	160	N

Note: * - either: New/Normal/Serious/Alert/Severe according to the values. Severe values are higher than alert values.

** - Typical (T) or Non-typical (N) IR spectra determined for oil sample.

PPO 1 – pure plant oil with phosphorous content < 10 ppm, PPO 2 – pure plant oil with phosphorous content > 10 ppm

Table 12: Engine oil analyses of tractor Fendt 612 LSA

PPO 2			Oil quality description/criteria				Working hours			Status
Parameter	**Unit**	**Limit values**	**New**	**Normal**	**Serious**	**Alert**	**4811**	**4934**	**4999**	
Basic number	mg KOH/g	(-) 25 – 35 % from initial value	10.5	6,8 - 10.5			7,1	7,4	8,3	S
Viscosity index		Significant change from initial value	137	137 – 150			180	166	162	S/A
IR spectrum		Typical (T)	T	T	N	N	T	T	T	T
Kinematic viscosity at 100 ºC	mm^2/s	(-) 15-20 % from initial value	15	12 - 15			12,02	12,03	12,95	
Kinematic viscosity at 40 ºC	mm^2/s	(+) 15-20 % from initial value	100	100 - 120			66,47	71,58	80,36	
Metals WD-XRF										
Aluminium (Al)	mg/kg	20-40		20-40	40-100	100-200	< 6	7	13	N
Chromium (Cr)	mg/kg	15-30		15-30	40-100	100-200	8	< 3	< 3	N
Copper (Cu)	mg/kg	30-50		30-50	40-100	100-200	< 3	< 3	< 3	N
Iron (Fe)	mg/kg	75-100		75-100	100-250	250-400	15	5	13	N
Lead (Pb)	mg/kg	30-50		30-50	50-100	100-200	< 3	< 3	< 3	N
Tin (Sn)	mg/kg	20-40		20-40			< 6	< 6	< 6	N
Non metals WD-XRF										
Silicon	mg/kg	25-40		25-40			7	21	42	N/S
Water	mg/kg	500 – 1000	<500	500 – 1000	>1000		180	180	380	N

Note: * - either: New/Normal/Serious/Alert/Severe according to the values. Severe values are higher than alert values.

** - Typical (T) or Non-typical (N) IR spectra determined for oil sample.

PPO 1 – pure plant oil with phosphorous content < 10 ppm, PPO 2 – pure plant oil with phosphorous content > 10 ppm

5.3 Land Rover Defender

Basic number of motor oil was higher than limit value for all three samples of motor oil. Viscosity index was significantly higher in two cases of motor oil samples. Kinematic viscosity (most important value for motor oils) at 100° C was in one oil sample higher than limit value. Kinematic viscosity at 40 °C or 100 °C measures a lubricant's resistance to flow (fluid thickness) at temperature and is considered an oil's most important physical property. Depending on lube grade, viscosity is tested at 40 and/or 100° C. Kinematic viscosity at 100 °C for motor oil SAE 15 W – 40 is between 12, 5 – 16, 3 mm^2 /s.

Engine oil from laboratory engine had once higher iron and once chromium amount of particles (iron and chromium particles had higher amount than initial value). Other metals were under recommended limits, only lead was once in higher amount in comparison with limit value for it. Quantity of silicon was higher once (this is connected with dirt from outside air). Water was always bellow the limits for permitted water content in engine oils. After every adding of new part of oil or complete exchange engine oil (disassembling and assembling of engine for control of deposits on cylinders, pistons and other parts of engine) content of copper and iron particles rapidly dropped to normal. Cylinder, piston and piston rings were after openings and measurements in normal conditions (they were not replaced with new parts). IR spectrum was also done and was typical for used motor oil. Also conclusion from IR spectrum was that in the every sample of engine oil on analysis was always some part of pure plant oil (unburned pure plant oil diluted in engine oil). But this was not bigger problem, because after every taking of sample of motor oil from engine, motor oil in engine was refreshed with added part of new – fresh motor oil.

Conclusions

Limit values for wear metals (microscopic level) were exceeded in the case of off-road vehicle Land Rover for iron, chromium and lead. There is also possibility that metal particles (especially for chromium and iron) were for longer period at oil pan, because oil was only partial refreshed when quantity taken for sampling was replaced with fresh oil. Only after opening the engine for estimating the condition of engine (cylinder, pistons, piston rings, nozzles etc.), motor oil pan was washed and oil completely exchanged with new.

Origin of iron in the motor oil specimen can be from different parts of engine like: cylinder block, valves, rocker arm shaft, piston pins, roller bearings (with chromium), timing wheels etc. Rare, residues can be from ferrocene which is fuel additive for soot reduction. Origin from chromium is from piston rings, crankshaft bearings, piston pins, exhaust valves, gaskets, guide bushes. Aluminium and chromium are usually found in combination with silicon in engines. Dust causes wear of most aluminium pistons, piston rings with chromium and engine cylinder (iron) wear. Lead usually comes with tin and copper. Origin in oil specimen is from rod bearings, nearly all running surfaces of plain bearings and soldered joints in combination with tin. Some part of pure plant oil was also diluted in motor oil but this not influenced on higher content of wear metals in engine oil. Why dilution can be problem and how fuel (pure plant oil) was diluted. Quality of pure plant oil burning is lower in comparison with mineral diesel fuel because pure plant is not atomized in very small fuel droplets like mineral diesel fuel. Bigger droplets will not totally burn or time needed for its burning will be longer and small part of unburned fuel will dilute in engine oil.

Pure plant oil dilute engine oil, diluted engine can influence on increased wear rates of engines. In fuel combustion all delivered fuel (pure plant oil or biodiesel) will not burn fully. Some fuel will pass between piston rings and cylinder wall to the crankcase where it dilutes or mixes with the engine oil for lubricating oil. In the case of mineral diesel fuel mixed with engine oil the heat in the crankcase will evaporate mineral diesel fuel. Biodiesel or pure plant oil will not evaporate easily. Engine oil diluted with biodiesel or pure plant oil will change viscosity to lower value and lubricity. In diluted engine oil also characteristics of anti wear additives in oil can change.

Dimensions of cylinders and pistons on laboratory engine, off-road vehicle and both tractors after every opening of engines were bellow limits for wear of engines. Cylinders and pistons were without damages (we do not need to replace pistons or rings etc.).

Solution for future use of engine oils

Changing intervals for engine oil can be halved in comparison with normal intervals for engine oils and quality of engine oil will not be critical.

Table 13: Engine oil analyses on off-road vehicle Land Rover

PPO 2			**Oil quality description/criteria**				**Number of kilometers**			**Sta-tus**
Parameter	**Unit**	**Limit values**	**New**	**Nor-mal**	**Seri-ous**	**Alert**	**194066**	**194910**	**199965**	
Basic number	mg KOH/g	(-) 25 – 35 % from initial value	10.5	6,8 - 10.5			16,5	16	12,5	S/A
Viscosity index		Significant change from initial value	137	137 – 150			165	158	142	N/S
IR spectrum		Typical (T)	T	T	N	N	T	T	T	T
Kinematic viscosity at 100 °C	mm^2/s	(-) 15-20 % from initial value	15	12 - 15			19,45	14,19	15,19	N/A
Kinematic viscosity at 40 °C	mm^2/s	(+) 15-20 % from initial value	100	100 - 120			135,0	92,44	111,9	N/S
Metals WD-XRF										
Aluminium (Al)	mg/kg	20-40		20-40	40-100	100-200	23	8	16	N
Chromium (Cr)	mg/kg	15-30		15-30	40-100	100-200	66	15	22	N/S
Copper (Cu)	mg/kg	30-50		30-50	40-100	100-200	22	6	12	N
Iron (Fe)	mg/kg	75-100		75-100	100-250	250-400	282	84	97	N/A
Lead (Pb)	mg/kg	30-50		30-50	50-100	100-200	93	26	50	N/S
Tin (Sn)	mg/kg	20-40		20-40			< 6	< 6	< 6	N
Non metals WD-XRF										
Silicon	mg/kg	25-40		25-40			65	25	41	N/S
Water	mg/kg	500 – 1000	<500	500 – 1000	>1000		120	880	110	N

Note: * - either: New/Normal/Serious/Alert/Severe according to the values. Severe values are higher than alert values.

** - Typical (T) or Non-typical (N) IR spectra determined for oil sample.

PPO 1 – pure plant oil with phosphorous content < 10 ppm, PPO 2 – pure plant oil with phosphorous content > 10 ppm

5.4 AGT 835

Engine oil from tractor AGT 835 had higher iron and cooper amount of particles in period (from 644 to 978 working hours). Limits for cooper and iron were higher than permitted limits. Other metals were under recommended limits. Quantity of silicon was higher in some periods (this is connected with contamination with casting residues in engine and dirt from outside air). Water was always bellow the limits for water content in engine oils. After every adding of new part of oil or complete exchange engine oil (disassembling and assembling of engine for control of deposits on cylinders, pistons and other parts of engine) content of copper and iron particles rapidly dropped to normal.

Cylinder, piston and piston rings were after openings and measurements in normal conditions (they were not replaced with new parts).

Kinematic viscosity at 40 °C or 100 °C measures a lubricant's resistance to flow (fluid thickness) at temperature and is considered an oil's most important physical property. Depending on lube grade, viscosity is tested at 40 and/or 100° C. Kinematic viscosity at 100 °C for motor oil SAE 15 W – 40 is between 12, 5 – 16, 3 mm^2 /s. All values for kinematic viscosity for samples of motor oils were normal (in accordance with low and high limit values for viscosity at 100 °C).

IR spectrum was also done. Conclusion from IR spectrum done was that in the every sample of engine oil on analysis was always some part of pure plant oil (unburned pure plant oil diluted in engine oil). But this was not bigger problem, because after every taking of sample of motor oil from engine, motor oil in engine was refreshed with added part of new – fresh motor oil.

Conclusions

Limit values (microscopic level) were exceeded in the case of tractor AGT 835 for iron and cooper. This can be explained partly that engine of tractor AGT 835 had small number of working hours at the start of tests. In starting of use new engines always is wear of some engine parts higher (cylinders, pistons etc.) because engine need time for run-in period. After every sampling interval, part of motor oil was taken and replaced with fresh oil (1,5 l). There is also possibility that metal particles (especially cooper and iron) were for longer period at oil pan, because oil was only partial refreshed when quantity taken for sampling was replaced with fresh oil. Only after opening the engine for estimating the condition of engine (cylinder, pistons, piston rings, nozzles etc.), motor oil pan was washed and oil completely exchanged with new.

Origin of iron in the motor oil specimen can be from different parts of engine like: cylinder block, valves, rocker arm shaft, piston pins, roller bearings (with chromium), timing wheels etc. Rare, residues can be from ferrocene which is fuel additive for soot reduction.

Some part of pure plant oil was also diluted in motor oil but this not influenced on higher content of wear metals in engine oil. Why dilution can be problem and how fuel (pure plant oil) was diluted. Quality of pure plant oil burning is lower in comparison with mineral diesel fuel because pure plant is not atomized in very small fuel droplets like mineral diesel fuel. Bigger droplets will not totally burn or time needed for its burning will be longer and small part of unburned fuel will dilute in engine oil.

Biodiesel or pure plant dilute engine oil, diluted engine can influence on increased wear rates of engines. In fuel combustion all delivered fuel (pure plant oil or biodiesel) will not burn fully. Some fuel will pass between piston rings and cylinder wall to the crankcase where it dilutes or mixes with the engine oil for lubricating oil. In the case of mineral diesel fuel mixed with engine oil the heat in the crankcase will evaporate mineral diesel fuel. Biodiesel or pure plant oil will not evaporate easily. Engine oil diluted with biodiesel or pure plant oil will change viscosity to lower value and lubricity. In diluted engine oil also characteristics of anti wear additives in oil can change.

Dimensions of cylinders and pistons on laboratory engine and both tractors after every opening of engines were bellow limits for wear of engines. Cylinders and pistons were without damages (we do not need to replace pistons or rings etc.).

Solution for future use of engine oils

Changing intervals for engine oil can be halved in comparison with normal intervals for engine oils and quality of engine oil will not be critical.

Table 14: Engine oil analyses of tractor AGT 835

PPO 2			Oil quality description/criteria				Working hours				Status
Parameter	**Unit**	**Limit values**	**New**	**Normal**	**Serious**	**Alert**	**569**	**644,5**	**776**	**879**	
Basic number	mg KOH/g	(-) 25 – 35 % from initial value	10.5	6,8 - 10.5			10,6	12	10,2	11	N/S
Viscosity index		Significant change from initial value	137	137 – 150			136	175	163	148	N/S
IR spectrum		Typical (T)	T	T	N	N	T	T	T	T	T
Kinematic viscosity at 100 ºC	mm^2/s	(-) 15-20 % from initial value	15	12 - 15			13,03	15,04	15,3	15,17	N
Kinematic viscosity at 40 ºC	mm^2/s	(+) 15-20 % from initial value	100	100 - 120			94,26	90,62	99,47	107,5	N/S
Metals WD-XRF											
Aluminium (Al)	mg/kg	20-40		20-40	40-100	100-200	< 6	13	11	10	N
Chromium (Cr)	mg/kg	15-30		15-30	40-100	100-200	20	26	24	22	N
Copper (Cu)	mg/kg	30-50		30-50	40-100	100-200	13	55	106	128	N/A
Iron (Fe)	mg/kg	75-100		75-100	100-250	250-400	49	214	214	214	N/S
Lead (Pb)	mg/kg	30-50		30-50	50-100	100-200	5	18	15	15	N
Tin (Sn)	mg/kg	20-40		20-40			< 6	< 6	7	7	N
Non metals WD-XRF											
Silicon	mg/kg	25-40		25-40			63	108	69	52	S/A
Water	mg/kg	500 – 1000	<500	500 – 1000	>1000		290	< 30	160	120	N

Note: * - either: New/Normal/Serious/Alert/Severe according to the values. Severe values are higher than alert values.

** - Typical (T) or Non-typical (N) IR spectra determined for oil sample.

PPO 1 – pure plant oil with phosphorous content < 10 ppm, PPO 2 – pure plant oil with phosphorous content > 10 ppm

Table 15: Engine oil analyses of tractor AGT 835

PPO 2			Oil quality description/criteria				Working hours				Sta-tus
Parameter	**Unit**	**Limit values**	**New**	**Nor-mal**	**Seri-ous**	**Alert**	**978**	**1078**	**1179**	**1277**	
Basic number	mg KOH/g	(-) 25 – 35 % from initial value	10.5	6,8 - 10.5			11,5	13,9	13,2	12,6	S/A
Viscosity index		Signifi-cant change from initial value	137	137 – 150			146	146	147	144	N
IR spec-trum		Typical (T)	T	T	N	N	T	T	T	T	T
Kinematic viscosity at 100 ºC	mm^2/s	(-) 15-20 % from initial value	15	12 - 15			14,9	14,08	14,05	14,03	N
Kinematic viscosity at 40 ºC	mm^2/s	(+) 15-20 % from initial value	100	100 - 120			106,3	98,73	97,87	99,04	N/S
Metals WD-XRF											
Alumini-um (Al)	mg/kg	20-40		20-40	40-100	100-200	10	8	< 6	8	N
Chromium (Cr)	mg/kg	15-30		15-30	40-100	100-200	19	21	20	18	N
Copper (Cu)	mg/kg	30-50		30-50	40-100	100-200	127	9	7	6	N/A
Iron (Fe)	mg/kg	75-100		75-100	100-250	250-400	174	73	72	78	N/S
Lead (Pb)	mg/kg	30-50		30-50	50-100	100-200	17	< 3	< 3	< 3	N
Tin (Sn)	mg/kg	20-40		20-40			9	< 6	< 6	< 6	N
Non met-als WD-XRF											
Silicon	mg/kg	25-40		25-40			37	29	22	23	N
Water	mg/kg	500 – 1000	<500	500 – 1000	>1000		70	160	310	130	N

Note: * - either: New/Normal/Serious/Alert/Severe according to the values. Severe values are higher than alert values.

** - Typical (T) or Non-typical (N) IR spectra determined for oil sample.

PPO 1 – pure plant oil with phosphorous content < 10 ppm, PPO 2 – pure plant oil with phosphorous content > 10 ppm

Table 16: Engine oil analyses of tractor AGT 835

PPO 2			Oil quality description/criteria						Status
Parameter	**Unit**	**Limit values**	**New**	**Normal**	**Serious**	**Alert**	**1368**	**1430**	
Basic number	mg KOH/g	(-) 25 – 35 % from initial value	10.5	6,8 - 10.5			11,3	11,8	S
Viscosity index		Significant change from initial value	137	137 – 150			143	141	N
IR spectrum		Typical (T)	T	T	N	N	T	T	T
Kinematic viscosity at 100 ºC	mm^2/s	(-) 15-20 % from initial value	15	12 - 15			14,06	14,09	N
Kinematic viscosity at 40 ºC	mm^2/s	(+) 15-20 % from initial value	100	100 - 120			100,2	101,6	N
Metals WD-XRF									
Aluminium (Al)	mg/kg	20-40		20-40	40-100	100-200	6	< 6	N
Chromium (Cr)	mg/kg	15-30		15-30	40-100	100-200	14	11	N
Copper (Cu)	mg/kg	30-50		30-50	40-100	100-200	6	6	N
Iron (Fe)	mg/kg	75-100		75-100	100-250	250-400	53	44	N
Lead (Pb)	mg/kg	30-50		30-50	50-100	100-200	< 3	< 3	N
Tin (Sn)	mg/kg	20-40		20-40			< 6	< 6	N
Non metals WD-XRF									
Silicon	mg/kg	25-40		25-40			18	15	N
Water	mg/kg	500 – 1000	<500	500 – 1000	>1000		120	200	N

Note: * - either: New/Normal/Serious/Alert/Severe according to the values. Severe values are higher than alert values.

** - Typical (T) or Non-typical (N) IR spectra determined for oil sample.

PPO 1 – pure plant oil with phosphorous content < 10 ppm, PPO 2 – pure plant oil with phosphorous content > 10 ppm

Table 17: Overview of the parameters considered regarding used engines oil quality, related analytical methods/ standards, recommended limited values (Petrol laboratory) and used oil quality criteria.

				Oil quality description/criteria*			
Parameter	**Unit**	**Method/standard**	**Limit values**	**New**	**Normal**	**Serious**	**Alert**
Base number	mg KOH/g	SIST ISO 3771	+25–35 %	10.5	10.5 – 14.2		
Viscosity index	-	SIST ISO 2909	(Sign. Change)	137	137 – 150		
IR spectrum	-	DIN 51451	Typical (T)**	T	T	N	N
Kinematic viscosity 100 ºC	mm^2/s	Mod. ASTM D 445	+15-20 %	15	15-20		
Kinematic viscosity 40 ºC	mm^2/s	Mod. ASTM D 445	+15-20 %	100			
Metals WD-XRF							
Aluminium (Al)	mg/kg	PML.07.16	20-40		20-40	40-100	100-200
Chromium (Cr)	mg/kg	PML.07.16	15-30		15-30	40-100	100-200
Copper (Cu)	mg/kg	PML.07.16	30-50		30-50	40-100	100-200
Iron (Fe)	mg/kg	PML.07.16	75-100		75-100	100-250	250-400
Lead (Pb)	mg/kg	PML.07.16	30-50		30-50	50-100	100-200
Tin (Sn)	mg/kg	PML.07.16	20-40		20-40		
Non metals WD-XRF							
Silicon	mg/kg	PML.07.16	25-40		25-40		
Water	mg/kg	Mod. ASTM D 6304	500 – 1000	<500	500 – 1000	>1000	

Note: * - either: New/Normal/Serious/Alert/Severe according to the values. Severe values are higher than alert values.

** - Typical (T) or Non-typical (N) IR spectra determined for oil sample.

6. ECONOMICS OF FUEL, MOTOR OIL, AND OTHER REPLACEMENT MATERIALS CONSUMPTION ON VEHICLES AND LABORATORY ENGINE

Fuel consumption of all included engines was established through measurement of fuel volume consumed in time unit for tractor and laboratory engine and at distance unit for off-road vehicle.

Average consumption was calculated from total volume of consumed fuel and total time or total number of kilometers covered during whole period. Fuel consumption of laboratory engine was calculated daily.

Laboratory engine was converted on the way that every cylinder of three cylinder diesel engine worked at the same time on one fuel (first cylinder on mineral diesel fuel, second on pure plant oil and third on biodiesel).

Load on the laboratory engine was the same for purpose of tribological research (influence of different fuels on engine wear and life of engine).

Table 18: Fuel consumption with mineral diesel fuel

	Land Rover	AGT 835	Fendt 612 LSA	Engine Lombardini
Costs of mineral diesel fuel (EUR/l)	1,365	1,365	1,365	1,365
Fuel consumption l/h (20 – 26 month)	-	*3,0	*8,33	1,31 l/Wh
Fuel consumption l/h (32 – 39 month)	-	*1,27	*7,89	1,0 l/Wh
Fuel consumption (20 – 26 month) (l/100 km)	*13,18 l/100 km	-	-	-
Fuel consumption (32 – 39 month) (l/100 km)	*12,18 l/100 km	-	-	-
Costs of fuel (20 – 26 month) (EUR/h)	-	4,09	11,37	1,78 EUR/kWh
Costs of fuel (32 – 39 month) (EUR/h)	-	1,73	10,76	1,36 EUR/kWh
Costs of fuel (20 – 26 month) (EUR/100 km)	17,99 EUR	-	-	-
Costs of fuel (32 – 39 month) (EUR/100 km)	16,62 EUR	-	-	-
Costs of fuel (20 – 26 month) (EUR/100 h)	-	409	1137	178
Costs of fuel (32 – 39 month) (EUR/100 h)	-	173	1076	136
Costs of oil, filters, work (EUR/5504 km)	0,0159 EUR/km 1 x exchange			
Costs of oil, filters, work (EUR/5298 km)	0,0166 EUR/km 1 x exchange	-	-	-
Costs of oil, filters, work (EUR/153,16 h)	-	-	-	0,523 EUR/h 1 x exchange
Costs of oil, filters, work (EUR/627,5 h) (	-	-	-	0,767 EUR/h 6 x exchanges
Costs of oil, filters, work (EUR/419 h)	-	0,706 EUR/h 4 x exchang-es	-	-
Costs of oil, filters, work (EUR/963,2 h)	-	0,691 EUR/h 9 x exchang-es	-	-
Costs of oil, filters, work (EUR/324 h)	-	-	0,671 EUR/h 1 x exchange	-
Costs of oil, filters, work (EUR/390 h)	-	-	0,558 EUR/h 1 x exchange	-

In table 18 are calculated values for mineral diesel consumption on vehicle in months (20 – 26) and (32 – 29). On this way is possible to compare mineral diesel fuel consumption with pure plant oil consumption (measured). For the consumption of mineral diesel fuel was assumed that is approximately the same as the consumption of pure plant oil. Values for laboratory engine for mineral diesel fuel, pure plant oil and biodiesel were measured in laboratory conditions.

Table 19: Fuel consumption with pure plant oil 100 %

	Land Rover	AGT 835	Fendt 612 LSA	Engine Lombardini
Costs of pure plant oil with added tax 20 % EUR/l	1,09	1,09	1,09	1,09
Costs of pure plant oil with added duty tax 0,43 EUR/l	1,52	1,52	1,52	1,52
Fuel consumption l/h (20 – 26 month)	-	3,0	8,33	1,39 l/Wh
Fuel consumption l/h (32 – 39 month)	-	1,27	7,89	1,04 l/Wh
Fuel consumption l/100 km (20 – 26 month)	13,18 l/100 km	-	-	-
Fuel consumption l/100 km (32 – 39 month)	12,18 l/100 km	-	-	-
Costs of fuel (20 – 26 month) (EUR/h)	-	4,56	12,66	2,11
Costs of fuel (32 – 39 month) (EUR/h)	-	1,93	11,99	1,58
Costs of fuel (20 – 26 month) (EUR/100 km)	20,03	-	-	-
Costs of fuel (32 – 39 month) (EUR/100 km)	18,51	-	-	-
Costs of fuel (20 – 26 month) (EUR/100 h)	-	456	1266	211
Costs of fuel (32 – 39 month) (EUR/100 h)	-	193	1199	158
Costs of oil, filters, work (EUR/5504 km)	0,0320 EUR/km 2 x exchange	-	-	-
Costs of oil, filters, work (EUR/5298 km)	0,0332 EUR/km 2 x exchange	-	-	-
Costs of oil, filters, work (EUR/153,16 h)	-	-	-	1,047 EUR/h 2 x exchange
Costs of oil, filters, work (EUR/627,5 h) EUR/h	-	-	-	1,534 EUR/h 12 x exchang-es
Costs of oil, filters, work (EUR/419 h)	-	1,412 EUR/h 8 x exchanges	-	-
Costs of oil, filters, work (EUR/963,2 h) EUR/h	-	1,382 EUR/h 18 x ex-changes	-	-
Costs of oil, filters, work (EUR/324 h) EUR/h	-	-	1,343 EUR/h 2 x exchange	-
Costs of oil, filters, work (EUR/390 h) EUR/h	-	-	1,116 EUR/h 2 x exchange	-

Values for pure plant oil consumption were estimated in everyday use of vehicles (table 19.).

Values for laboratory engine for mineral diesel fuel, pure plant oil and biodiesel were estimated in laboratory conditions with loading engine with measuring brake or DC generator.

Table 20: Fuel consumption with biodiesel B 100

	Land Rover	AGT 835	Fendt 612 LSA	Engine Lombardini
Costs of biodiesel EUR/l	1,23	1,23	1,23	1,23
Fuel consumption l/h (20 – 26 month)	-	*3,3	*9,16	1,26 l/Wh
Fuel consumption l/h (32 – 39 month)	-	*1,39	*8,67	1,1 l/Wh
Fuel consumption l/100 km (20 – 26 month)	14,49 l/100 km	-	-	-
Fuel consumption l/100 km (32 – 39 month)	13,39 l/100 km	-	-	-
Costs of fuel (20 – 26 month) EUR/h	-	4,09	11,26	1,54
Costs of fuel (32 – 39 month) EUR/h	-	1,70	10,66	1,35
Costs of fuel (20 – 26 month) EUR/100 km	17,82	-	-	-
Costs of fuel (32 – 39 month) EUR/100 km	16,46	-	-	-
Costs of fuel (20 – 26 month) EUR/100 h	-	409	1126	154
Costs of fuel (32 – 39 month) EUR/100 h	-	170	1066	135
Costs of oil, filters, work (EUR/5504 km)	0,0320 EUR/km 2 x exchange	-	-	-
Costs of oil, filters, work (EUR/5298 km)	0,0332 EUR/km 2 x exchange	-	-	-
Costs of oil, filters, work (EUR/153,16 h)	-	-	-	1,047 EUR/h 2 x exchange
Costs of oil, filters, work (EUR/627,5 h)	-	-	-	1,534 EUR/h 12 x ex-changes
Costs of oil, filters, work (EUR/419 h)	-	1,412 EUR/h 8 x exchang-es	-	-
Costs of oil, filters, work (EUR/963,2 h)	-	1,382 EUR/h 18 x ex-changes	-	-
Costs of oil, filters, work (EUR/324 h)	-	-	1,343 EUR/h 2 x ex-change	-
Costs of oil, filters, work (EUR/390 h)	-	-	1,116 EUR/h 2 x ex-change	-

In table 20 are calculated values for biodiesel consumption on vehicle in months (20 – 26) and (32 – 29). On this way is possible to compare biodiesel fuel consumption with pure plant oil consumption (measured). For the consumption of biodiesel fuel was assumed that is approximately 10 % higher than consumption of the pure plant oil.

Values for laboratory engine for mineral diesel fuel, pure plant oil and biodiesel were measured in laboratory conditions with loading engine with measuring brake or DC generator.

7. WEAR OF ENGINES

7.1 Weighing of engine pistons

After disassembly of engine, pistons were carefully cleaned with solvent, especially in the area of piston rings. The top surface of pistons was stayed untouched. After drying pistons with rings were weighted. Than from pistons were removed carbon deposits and after cleaning another weighing was carried out.

7.2 Dimensions of engine parts

After second weighing piston diameters were measured with appropriate micrometer. Because of shape of pistons, measurements were carried out just at top and bottom edge in the direction of piston pin and perpendicular to this direction.

Bore of engine cylinders were measured at bottom, middle and top position and just in one direction, because micrometer have three measuring tips placed at 120° so diameter cannot be measured in two directions.

7.3 Photographs of engine parts

We photographed the pistons from the top and sides, fuel injectors and engine head from the bottom up. Pistons were photographed before and after cleaning.

7.4 Weight of pistons

7.4.1 Tractor AGT 835 Agromehanika

Mass [g]		No. of piston		
Date	Working hours	1	2	3
19.6.2009	500	507,31	507,34	507,16
20.9.2011	1429			
Row		508,00	507,09	507,11
After cleaning		506,69	506,65	506,72
Weight of depositions [g]		1,31	0,44	0,39
Wear compared to 19.6.2009		0,62	0,69	0,44

From the results we can see that on first piston was more carbon deposit than on other two. This can be also seen on pictures of row pistons. The difference between weight from last measurement and first one show that wear of pistons is quite uniform.

7.4.2 Engine Lombardini LWD 1503

Mass [g]		No. of piston		
Date	Working hours	1 (oil)	2 (B100)	3 (D2)
21.7.2009	0	510,5	510,81	510,49
20.9.2011	652			
Row		510,88	511,37	511,06
After cleaning		510,48	510,79	510,47
Weight of depositions [g]		0,4	0,58	0,59

Wear compared to 21.7.2009		0,02	0,02	0,02

On the basis of weighing we can conclude that less deposit was on first piston, which running on plant oil. Another two pistons, running on biodiesel and mineral diesel fuel, had almost the same amount of deposit. The wear of all pistons was uniform and barely detectable.

7.5 Dimensions of pistons and cylinders

7.5.1 Tractor AGT 835 Agromehanika

Diameter of pistons [mm]. (T – diameter at top of piston, B – diameter at bottom of piston)

	Piston diameter [mm]											
	1				2				3			
	Pin direction		Perpendicular to pin		Pin direction		Perpendicular to pin		Pin direction		Perpendicular to pin	
	T	B	T	B	T	B	T	B	T	B	T	B
19.6.2009	87,57	87,58	87,63	87,93	87,61	87,57	87,61	87,93	87,60	87,58	87,62	87,95
20.9.2011	87,55	87,56	87,61	87,92	87,50	87,57	87,59	87,92	87,50	87,56	87,60	87,92
Differ-ence	0,02	0,02	0,02	0,01	0,11	0,00	0,02	0,01	0,10	0,02	0,02	0,03

It can be seen, that the highest wear was on piston 2 and 3 at the top in pin direction. Other differences are very small.

The diameters of cylinder bore are the same like at first measurement at 500 working hours so the wear of cylinders cannot be detected through measurement of diameter.

7.5.2 Engine Lombardini LWD 1503

Diameter of pistons [mm]. (T – diameter at top of piston, B – diameter at bottom of piston)

	Piston diameter [mm]											
	1 (oil)				2 (B100)				3 (D2)			
	Pin direction		Perpendicular to pin		Pin direction		Perpendicular to pin		Pin direction		Perpendicular to pin	
	T	B	T	B	T	B	T	B	T	B	T	B
21.7.2009	87,53	87,55	87,61	87,93	87,49	87,58	87,59	87,93	87,49	87,55	87,59	87,92
20.9.2011	87,50	87,51	87,59	87,92	87,48	87,56	87,57	87,90	87,48	87,53	87,57	87,91
Differ-ence	0,03	0,04	0,02	0,01	0,01	0,02	0,02	0,03	0,01	0,02	0,02	0,01

There is no remarkable difference that can point to excessive wear.

At cylinder diameter measurement there are also no differences between last and first measured diameters. That means that wear cannot be detected through diameter measurement.

	Piston 1	Piston 2	Piston 3
Beginning at 500 WH			
After 929 WH			
			
	Injector 1	Injector2	Injector3
			

Figure 15: Photos of tractor AGT 835 engine parts after disassembling the engine

Figure 16: Clean pistons before assembly of engine.

From pictures it can be seen that on first piston was more carbon deposits like on another. Similar situation was also on engine head. If we compare injectors, there cannot be seen big difference. There was a significant amount of deposits on the injectors too.

	Piston 1 – PPO	Piston 2 – B100	Piston 3 – D2
Beginning – 0 WH			

After 652 WH				
				
		Injector 1 – PPO	Injector2 – B100	Injector3 – D2
				

Figure 17: Photos of tractor AGT 835 engine parts after disassembling the engine, 20.9.2011 after 652 working hours.

Figure 18: Clean pistons before assembly of engine.

Pistons and engine head of Lombardini engine were pretty clean without excessive amount of deposits. There was also no visible difference between them. Smallest quantity of deposits can be seen on middle injector which sprays biodiesel fuel. But about the same quantity of deposits can be observed on injector for mineral diesel fuel and for pure plant oil.

7.6 CONCLUSION

Energetic use of plant oil in engines (diesel engines on different road and off-road vehicles, cogeneration units for the production of electric and thermal energy, ships, railways, etc.) is the current alternative for fossil oil or mineral diesel oil. For the driving of modified diesel engines, beside crude and refined plant oils, waste edible oils and animal fat may be used. The characteristics of combustion of plant oils are very similar to those of mineral diesel fuel but their viscosity is too high for modern high pressure fuel pumps and other elements in the fuel supply system. High viscosity causes plugging of fuel pipes, filter and high pressure injection nozzles. Several researchers have determined that high viscosity resulted in incomplete atomisation (dispersion of fuel drops) of plant oil resulting in prevention of complete combustion of larger fuel drops and production of carbon plaque. Consequently, plant oils can not be applied directly in diesel engines, so they have to be modified. They may be modified in two ways. With one-tank system the tractor or vehicle engine is driven exclusively by plant oil. Since this system is quite demanding to build in, the two-tank system is preferably used today. The two-tank system requires mineral diesel fuel (instead of mineral diesel oil biodiesel may be used) to start the engine and to use before stopping it. Several larger manufacturers of engines and tractors in Europe offered modified diesel engines which can use plant oil for driving.

The use of pure plant oil can generate substantial savings in CO_2 emissions. In the case of a tractor AGT 835 using pure plant oil on 500 working hours per year may lead to savings of up to 2.5 tons of CO_2 compared with using mineral diesel fuel. Using pure plant oil in a Tractor Fendt 612 on 500 working hours/ year may save up to 6.9 tons of CO_2 compared with using mineral diesel fuel.Regarding the off-road car Land Rover Defender with travelled 10.000 km/ year the use of pure plant oil can save up to 2.2 tons of CO_2 compared to mineral diesel fuel. The greatest savings can be achieved using the tractor Fendt Favorit 612. All vehicles together can annually save up to 11.6 tons of CO_2, which also means less emissions of greenhouse gases into the atmosphere.

Using pure plant oil in a laboratory engine on 500 kWh can save up to 800 kg of CO_2 (one cylinder of engine fuelled with pure plant oil), compared with mineral diesel fuel. Also in this case, the saving is not negligible. CO_2-savings with use of biodiesel in laboratory engine is lower than the CO_2 savings by using pure plant oil.

8. BIBLIOGRAPHY

Godeša, T., Jejčič, V., Poje, T.: Characteristics of a tractor engine using mineral and biodiesel fuels blended with rapeseed oil, Scientia Agricola, vol. 67, University of Sao Paulo, Piracicaba, Brasil, 2010.

Jejčič, V., Poje, T., Godeša, T.: possibilities of running tractor and vehicles by plant oil, Actual tasks on Agricultural Engineering, Proceedings of the 36th International Symposium on Agricultural Engineering, Opatija, 2008.

Knuth, W.H., Winkler, M.: Impementation of a 500 h engine test cycle and field testing of Deutz Common-Rail Engines in Heavy Duty Euro IV Truck Applications for Release of Biodiesel, UFOP Project No. 540/080; Final Report; Deutz AG, Köln; 2009.

MAN B & W Diesel AG, Bio fuels for Diesel Engines, 2004.

Mittelbach, M., Remschmidt, C.: Biodiesel, The comprehensive handbook, Graz 2004.

Oel Checker, Typical limit values for motor oils from diesel engines – stationary or non stationary, Wear metals, contaminants and additives, Oelcheck Gmbh, Brannenburg, Germany, 2010.

Riva, G., Sissot F.: CIGR Handbook of Agricultural Engineering, Volume V - Energy & Biomass Engineering, chap. 3.1.2, Biomass Resources, ASAE, St. Joseph MI USA, 1999.