Ethanol enriched biodiesel as a fuel for compression ignition engines

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ABSTRACT: In the Czech Republic the increased utilization of the biofuels, especially for diesel engines, has been registered in the last ten years. The rape-seed oil based fuels – called biodiesel, is the most extended. The use of rape-seed oil brings a good ecological and agronomic aspect, e.g. positive energetic and CO_2 balance, biological decomposition, etc. A special attention should be paid for the emissions. The paper presents the practical results of the performance with the commercially available biodiesel and their mixtures with different quantity of fermented ethanol. The testing was realized with an unmodified AVIA 712.18 truck engine and an unmodified ZETOR 7701 tractor engine according to thirteen-points homologation test method EHK R49 (ČSN EN ISO 8178-4). Biodiesel NATURDIESEL, according to the Czech Standard ČSN 65 6508, served as a basis for fuel blends and such a comparison fuel. Based on the experiment, it can be said, that the most suitable fuel blend is biodiesel + 2% addition of fermented bioethanol according to following points. This addition significantly reduces the NO_x emissions. At the AVIA engine the reduction is about 54% in comparison with non-additived fuel. With the Zetor engine, it is decreased 88% of its primary value. Even in cause of smokiness, the situation is similar favourable. The power output parameters are almost constant. No significant increase of fuel consumption has been observed. However, there is higher share of unburned hydrocarbons in dependence on increased alcohol content. In this case, the lower concentration of alcohol in fuel blend is advantageous, which is in accordance to the biodiesel with 2% addition of alcohol. Higher share of ethanol is not interesting from the point of view of fuel requirement and even from the economic point of view, because the price of these fuel blends increases, due to the co-solvent addition.

Keywords: biodiesel; alcohol; fuel blend; emissions

Biodiesel is a fuel produced from renewable sources such a substitute for petroleum based fuels, especially for diesel engines. The best candidates for this purpose are vegetable oils. The use of raw vegetable oil called "biodiesel of 0. generation" is not possible in the conventional diesel engines due to the oil attributes. High viscosity means problems with fuel injection, problems with crankcase lubricant polymerization, etc. Only special engine construction – for example Elsbett motor – can directly use raw vegetable oil.

These negative attributes can be reduced by following ways: transesterification, or by transesterification and blending with petrol diesel fuel.

Transesterification is the conversion process based on reaction of vegetable oil with methanol in the presence of catalyst to yield glycerin and biodiesel (chemically called methyl ester) – this fuel is called "biodiesel of I. generation". The conversion involves transesterification of the oil triglycerides to mono-esters of the component fatty acids. To accomplish this conversion, raw rapeseed oil is treated at temperatures of 60–70°C with methyl alcohol at the presence of potassium hydroxide as a catalyst. During the process, the glycerol, which is produced is insoluble in the ester product, and being heavier, settles out carrying most of the dissolved KOH catalyst with it. Attributes of this fuel make it possible to use it in the conventional combustion engine with its minimal modification, especially in fuel ways. However, there are also some problems like imperfect burning and problems with polymerization, which are obstacles to this fuel extension.

Another way of vegetable oil utilization is blending of rape-seed methyl ester (RME) with petrol diesel fuel. The attributes of this fuel mixture are closely related to the petrol diesel fuel. The composition of the fuel mixture is 30–36% of rape-seed methyl ester and the rest is petrol diesel fraction (64–70%) and other additives, according to the Czech Standard (ČSN 65 6508). This fuel mixture is called "biodiesel of II. generation" and realize all ecological and engine requirements, such a biological decomposition.

Biodiesel has desirable degradation attributes that make this fuel environmentally suitable. The law order is 90% degraded at the end of 21 days according to CEC-L33-T-82 test. The diesel fuel was approximately 40% degraded after 28 days.

The use of biodiesel in a conventional diesel engine reduces emissions of carbon monoxide and unburned hydrocarbons (since the oxygen in biodiesel enables more complete combustion to CO_2) and reduces the sulphate fraction (biodiesel contains less than 24 ppm sulphur) and particular matter. Emissions of nitrogen oxides are either slightly reduced or slightly increased depending on the duty cycle and the engine.

MATERIALS AND METHODS

Testing and testing method

The testing was realized with an unmodified AVIA 712.18 truck engine and an unmodified ZETOR 7701 tractor engine according to thirteen-points homologation test method EHK R49 (ČSN EN ISO 8178-4). This method is applied to heavy performed compression ignition engines, e.g tractor engines. General principle of thirteen-points testing method is the utilization for group of motors with the similar properties and it is realized with minimum possible testing cycle to guarantee the typical performance of these engines. At this test, parameters are evaluated at five different loading regimes during mean and rated engine revolutions including three times at idle revolutions (Fig. 1).

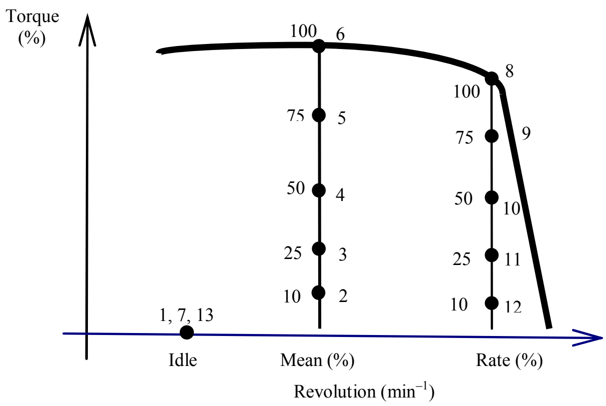

Fig. 1. The thirteen points test and sequence of testing points

Apparatuses and engine description

The properties of engines and the equipment which are used are followed:

Output brakes: Whirling electric dynamometer VD 110, 100kW engine output, connected with AVIA 712.18 engine.

Whirling electric dynamometer VD 250, 250kW engine output, connected with Zetor Z-7701 engine.

Speedometer: Universal counter TESLA BM 445 with sixty-claws reader on dynamometer shaft.

Fuel supply measurement: Automatic mass fuel gauges with possibility to switch over the 0–50 g and 0–100 g ranges.

Temperature measurement: Platinum resistance thermometers and diode thermometers.

Thermoelectric thermometer for exhaust gases temperature measurement.

Pressure measurement:

U-tubes with water filling.

Measurement of test conditions:

Hair hydrometer, micropressure recorder.

Emission measurement:

Smokiness: HARTRIGE MK 3 opacimeter.

Gaseous emissions of CO_2, CO, HC, O_2:

Four component analyzer NDIR INFRALYT 4000 with measurement ranges:

CO	0–10%;
CO_2	0–20%
HC	0–5,000 ppm
O_2	0–21%

NO_x emissions:

URAS 2T, NDIR gas analyzer: 0–5,000 ppm

Engines:

AVIA 712.18, Serial No. 132187 × 1139
Bore: D = 102 mm, number of cylinders i = 4
Stroke: Z = 110 mm
Volume of cylinders: V_M = 3,595 dm^3
Fuel injection pump: PP 4 M Ple 2491
Speed controller: RN 1M 250/1500
Jet injection: DOP 160 S 430-1436

ZETOR Z-7701, Serial No. 0101-2 25 5 88
Bore: D = 102 mm, number of cylinders i = 4
Stroke: Z = 120 mm,
Volume of cylinders: V_M = 3,922 dm^3
Fuel injection pump: PP 4 M 3137 S 0164
Speed controller: RV M 9001100 3300
Jet injection: DOP 160 S 430-1436

Engine tuning parameters like injection pressure, angle of pre-injection, etc. correspond to manufacturer basic adjustment.

The fuel blends with different content of alcohol were used for testing. Biofuel NATURDIESEL, according to the Czech Standard ČSN 65 6508, served as a basis for fuel blends and as a comparison fuel. Denotation and composition of fuels are in Table 1.

Equipment of engine testing laboratory at the Department of Cars and Tractors, Technical Faculty, Czech University of Agriculture in Prague were used during the measurement. Before experiment, detailed fuel analysis have been done by Prof. J. KOVÁŘ, Department of Chemistry, Faculty of Agronomy, Czech University of Agriculture in Prague. Based on elementary analysis of fuel samples, it is possible to determine theoretical heat value of blended fuels. Other important parameters like density, viscosity, distillation curve, etc. have been done too. For selected parameters see Table 1.

RESULTS OF MEASUREMENT

Evaluation of the fuel properties

The fuel blends have been evaluated from the point of view of fuel properties. The results as follows: basic fuel NATURDIESEL (0% of alcohol) is fully corresponding to the ČSN 65 6508, RME content correspond to the respective law (it means more than 30%). Also, the (C.F.P.P. – cold filter plugging point), physical and chemical properties are in standard limits

Table 1. Selected parameters of fuel blends

Parameter	Fuel blend/concentration of ethylalcohol (%)					
	0	1	2	4	6	8
Density at 15°C (kg/m^3)	832.15	834.2	831.47	829.97	831.2	830.2
Viscosity at 40°C (mm^2/s)	2.747	2.627	2.593	2.470	2.522	2.392
Heat value (kJ/kg)	42,134	41,955	41,780	41,444	41,125	40,822
Distillation curve beginning of distillation (°C)	187	79	80	76	79	79
10% point (°C)	210	198	201	191	190	190
50% point (°C)	283	269	271	270	270	295
95% point (°C)	385	345	354	339	344	343
Aniline point (°C)	71	72	65	62	73	74
Diesel index	54.3	58.5	57.3	59.8	61.7	59.4
Cetane index (accord. ASTM D 4737)	45.919	50.52	48.135	51.431	53.34	51.16
Saponification number (mg KOH/g)	61.720	57.063	55.677	52.964	54.981	52.332
Ester number	61.442	56.796	55.280	52,7156	54.687	52.038
RME content (%)	32.47	–	29.21	27.86	–	27.5
Acid number (mg KOH/g)	0.278	0.294	0.278	0.249	0.294	0.294
Water content (accord. Carl Fischer) (ppm)	267	379	267	278	1,200	1,600
Properties in low temp. conditions C.F.P.P. (no filterability) (°C)	–15	–15	–17	–19	–18	–24
Freezing point (°C)	–31	–34	–34	–34	–36	–38
Flash point (accord. P.M.) (°C)	61	53	58	55	51	49

too. It can be said, that NATURDIESEL fulfils the first rate biofuel.

However, increased content of ethanol means decreasing heat value (heat value of ethanol is only 27,332 kJ/kg), lower temperature at the begining of distillation and higher water content. Properties in low temperatures (mainly C.F.P.P.) are in limits.

Verification of the engine parameters and gas emissions

The results of the selected engine output and emission parameters evaluation are demonstrated in the graphs depending on the emission parameter in alcohol concentration. All parameters are calculated for standard atmospheric conditions.

Engine output and operation parameters

Reduced engine output: Both engines showed, that there are no significant differences in engine output among the biofuels with various share of alcohol, i.e. engine output is nearly constant in dependence of alcohol content.

Specific fuel consumption: Only trifling increase of specific fuel consumption of fuel blends with higher concentration of alcohol has been observed. Reason of this is the lower heat value and lower viscosity of the fuel with alcohol.

Exhaust gases temperature: There is a little bit of decrease in temperatures at higher alcohol concentration, due to the high evaporative heat of alcohol, which takes off the heat from combustion space.

Emission parameters

Smokiness: With regard to the high distribution of dates, it is not possible to exactly assess the course of this parameter. But, generally, it can be said, that quantity of the smokiness decrease at increased content of alcohol in fuel blend (Fig. 2), due to the lower viscosity and consequently to the better fuel injection. Amount of Zetor smokiness is about half lower than AVIA has, because the temperature in combustion space is higher and combustion is better.

CO emissions: CO is poisonous gas arising from the imperfect burning of carbon contained in the fuel. Primary cause of its existence is the lack of the oxygen in burned mixture. The lack of the oxygen can be local (in some cylinders of multicylinder engines, or in some parts of combustion space). Another cause is low reaction velocity of elementary oxidation processes, in which the CO is primary product of this reaction. The process deceleration in the phase of CO to CO_2 conver-

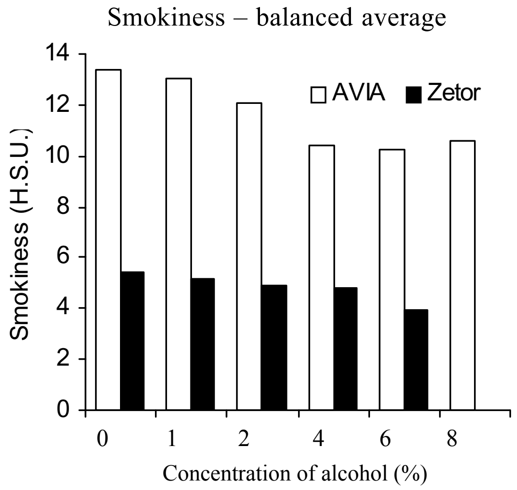

Fig. 2. Total smokiness emission amount

sion means higher concentration of CO in flue gases. This process also exists in places with extreme low reaction temperature, like narrow passages or nearness of cold sides.

There is an increasing CO emissions in dependence on increasing content of alcohol in both cases. Generally, the amount of CO in Zetor flue gases is higher, than AVIA has.

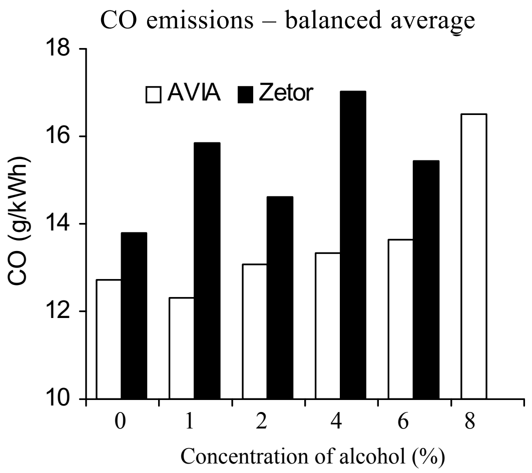

Fig. 3. Total CO emission amount

HC emissions: The unburned hydrocarbons arises under similar conditions like CO. Besides the negative influence on environment, it means also the loss of energy. Due to the oxidation of these hydrocarbons should be possible to enhance the heat brought to the combustion cycle.

Both engines showed increasing amount of unburned hydrocarbons at increasing concentration of alcohol in fuel blend. It could be explained by cooling of combustion space due to the high evaporation heat of alcohol.

NO_x emissions: These emissions arise as a product of the airy nitrogen oxidation in combustion space. The oxidation of nitrogen passes under the high temperatures and it is endothermic.

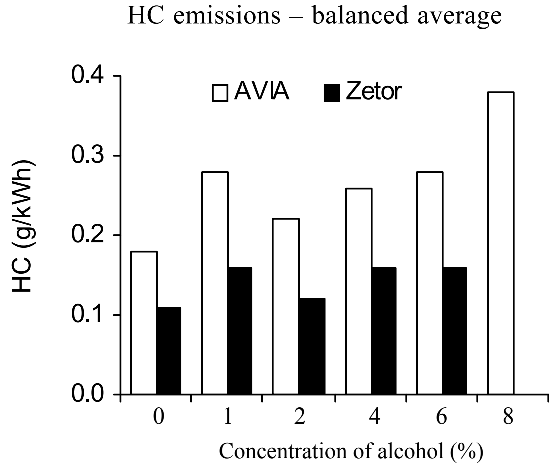

Fig. 4. Total HC emission amount

The results of this emissions measurement are very interesting. The significant decrease (80% in comparison with 0% fuel blend) was observed at Zetor engine. Whereas the outstanding decrease (50% in comparison with 0% fuel blend) in AVIA engine. However, increased share of alcohol, means the increased concentration of NO_x.

DISCUSSION

The results of the experiment are summarized and presented as a dependence of emission amount at concentration of alcohol in fuel blend. With regard to huge quantity of measured values, the total emission amount is calculated by means of balance coefficient, according to EHK R49. The aim of the experiment was to appreciate the addition of alcohol in biodiesel. Based on previous experiments, the optimal fuel blend was between 0% and 10% share of ethanol. During the experiment with biodiesel containing 0, 2, 4, 6 and 8% of alcohol, it has been observed, that significant changes of emission parameters sets in lower concentration. And because of, the next experiment with 1% fuel blend has been realized.

Problem is the stability of fuel blends from the point of view of solubility. The water contented in ethanol caused, that the alcohol is insoluble in biodiesel. Due to this, the addition of the so called co-solvent, is necessary. The tercial butanol (TBA) was used in this experiment. However, the price of this substance is high and it is amount increases the price of biofuel. Bioethanol for grocery purposes is pretentiously refined to remove the poisoned higher alcohols. The requirement of the bioethanol quality for fuel purposes is not so high, and because of the refination process can be dropped out to save the costs for this operation.

CONCLUSION

Based on the above mentioned results, it can be said, that the most suitable fuel blend is: biodiesel +2% addition of fermented bioethanol according to following points. This addition significantly reduces the NO_x emissions. At the AVIA engine the reduction is about 50% in comparison with non additived fuel (0% fuel blend). With the Zetor engine, it is decreased 80% of its primary value. Even in cause of smokiness, the situation is similarly favourable. The power output parameters are almost constant. No significant increase of fuel consumption has been observed. However higher share of unburned hydrocarbons related to increased alcohol content has been observed. In this case, the lower concentration of alcohol is advantageous, which is in accordance to the 2% fuel blend. Higher share of ethanol is not interesting from the point of view of fuel requirements and even from the economic point of view, because the price of these fuel blends increases, due to the co-solvent addition.

In the comparison to the commercially available petrol diesel, the total amount of emissions at the fuel blends (especially with small content of alcohol) was lower in all cases, which facilitates the realization of emission limits also at the older types of engines.

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Bionafta aditivovaná ethanolem jako palivo pro vznětové motory

ABSTRAKT: V České republice byl v posledních deseti letech zaznamenán nárůst ve využívání bionafty pro vznětové motory. Nejrozšířenější je bionafta na bázi řepkového oleje. Produkce řepkového oleje má řadu pozitivních ekologických a agronomických aspektů, jako je např. pozitivní CO_2 bilance, biologická rozložitelnost paliva atd. Zvláštní pozornost je třeba věnovat emisím. Příspěvek shrnuje výsledky provozních zkoušek palivových směsí bionafty s různými přídavky alkoholu. Provozní zkoušky byly prováděny na neupravovaných motorech AVIA 712.18 a ZETOR 7701 podle metodiky třináctibodového testu EHK R49 (ČSN EN ISO 8178-4). Jako výchozí a porovnávací palivo byla použita bionafta NATURDIESEL podle ČSN 65 6508. Na základě výsledků experimentu lze konstatovat, že nejvhodnější palivovou směsí je bionafta s přídavkem 2% kvasného ethanolu. Tento přídavek významně snižuje množství emisí NO_x. U motoru AVIA se množství této emise snížilo na 54 % a u motoru ZETOR na 88 % celkového množství naměřeného s bionaftou bez přídavku alkoholu. Příznivých výsledků bylo dosaženo rovněž v případě kouřivosti. Rozdíl mezi výkonovými parametry motorů u jednotlivých směsí nebyl zaznamenán. Rovněž nebyl zaznamenán významný nárůst měrné spotřeby paliva. Se zvyšujícím se podílem ethanolu ve směsi však bylo naměřeno vyšší množství CO a nespálených uhlovodíků. Z tohoto hlediska jsou výhodnější směsi s menším obsahem alkoholu, což opět odpovídá bionaftě s 2 % ethanolu. Vyšší koncentrace není žádoucí ani z hlediska palivářského, ani z hlediska ekonomického, protože zvyšující se koncentrace ethanolu ve směsi znamená nárůst ceny paliva v důsledku nutnosti většího přídavku kosolventu.

Klíčová slova: bionafta; alkohol; palivo; emise

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