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Influence of Higher Alcohols on the Combustion Pressure of Diesel Engine Operated with Rape Seed Oil

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ABSTRACT

To replace diesel fuel in IC engines, one of the most used alternatives is rape seed oil. In this research rape seed oil has been blended with higher alcohols as the 1-butanol and 2-propanol in 10 or 20 vol% to reduce viscosity. We present our results investigating the effect of these blends on the combustion process and on the emission. We describe the measurement system and the calculation methods applied for evaluation. Results show that both blends have significant effect on the pollutant emission, but the concrete effect may differ from blend to blend. The smoke emission significantly decreases, but there is an increment in the CO and THC emissions. NO_x emission slightly decreases in case of butanol, but increases in case of 2-propanol. Considering the combustion process, alcohol blends increase the intensity of the kinetic combustion, and decrease the length of the diffuse phase.

KEYWORDS

rape seed oil, higher alcohols, blends, emission, combustion process.

INTRODUCTION

Because of the regulations of environmental protection and considerably high depending on import, Europe like our country has to take some footsteps in the field of regenerative fuels. One of the most important application areas of regenerative fuels is transport and decentralised energy producing, which would be more significant in the future. The fuels of internal combustion engines can be interchangeable with regenerative fuels. The major disadvantage of vegetable oils is their inherent high viscosity leading poor fuel atomization, incomplete combustion, fuel injectors coking, ring carbonization and accumulation of fuel in the lubricating oil [21, 1, 20].

Fuel blending of vegetable oils with another fuel of lower viscosity is one technique that can be used to reduce the viscosity and allows the engine fuel system to handle the vegetable oil-fuel blends without any problem. The different blends of vegetable oil-diesel fuel were found to be successful as an engine fuel [10, 4, 19]. The results of the short term testing were encouraging; problems occurred in long-term engine durability tests. Hence, use of blends containing vegetable oils exceeding a different limits are impractical in both direct and indirect injection diesel engines, the NO_x, THC and particulate matter emissions increased.

On the other hand, in this blending context, simple alcohol (ethanol and methanol) has various advantages in comparison with diesel as a component of blends to be used in diesel engines: it is a renewable, it can be made by using already improved and demonstrated technologies. However, there are many obstacles of using alcohol in CI engines, which are listed as follows: it has limited solubility in diesel fuel. Phase separation and water tolerance in alcohol-vegetable oil blend fuel are crucial problem [6, 11, 2, 14, 7, 12, 5, 17]. It was found that additives were useful to adjust the fuel properties of the blends. In particular, the additives enhance phase stability and improve the cetane number in the blends.

The higher alcohols, i.e. C2-C4 alcohols have a number of advantages such as: they can be produced from the fermentation of glucoses from indirect hydration, or from the distillation of carbon hydrogen [13], lower viscosity of them, is one technique that can be used to reduce the viscosity of blends, their oxygen concentrations are higher, and thus their potential for particulate emissions reduction, THC emission is also higher etc. [22, 23]. Blending of vegetable oil with different higher alcohol concentrations is therefore expected to improve the fuel blends properties, combustion characteristics, reduce diesel fuel requirement and thus contribute in conserving a major commercial energy source. Consequently, this topic needs to be further investigated for a precise knowledge and widespread use of these fuels. For this reason, it is important to know the basic fuel properties of rape seed oil-higher alcohols blends.

We investigated 6 higher alcohol-rape seed oil mixture samples (2 samples 1-butanol - rape seed oil mixtures; 2 samples 2-propanol - rape seed oil mixtures) reference Diesel fuel and the natural rape seed oil. In the article we introduce our measuring system and the results of measured emissions at the adjustment for diesel oil.

MEASUREMENT SYSTEMS

The model CFR-F5 Cetane Method Diesel Fuel Rating Unit is a packaged version of the single cylinder, four-stroke cycle CFR Engine designed for compression-ignition testing of diesel fuel samples. The complete unit is known as the ”ASTM-CFR Engine” and is marked by American Society for Testing and Materials and the Coordinating Fuel Research Committee. A unique cylinder/cylinder head assembly with variable compression ratio and an indirect injection system assembles on the basic CFR-48D crankcase. The engine flywheel is belt connected to electronic synchronous-reluctance type motor acts to start the engine, and maintain constant engine speed [24, 3].

The cylinder head incorporates a cylinder pre-combustion chamber (Fig. 1) that is connected to the main combustion chamber by a turbulence passage. The injector nozzle sprays fuel into this chamber from one end while a variable compression plug controlled by a hand wheel mechanism blocks the opposite end. This plug can be moved in and out of the pre-combustion chamber to cause changes in compression ratio with the engine operating.

Detection of the time of injection and the start of combustion are sensed by electromagnetic pickups while two reference pickups sense the crankshaft position at prescribed points in the combustion cycle. Signals from these pickups are input to a Cetane Meter which digitally displays injection time (advance) and ignition delay in crank angle degrees.

Engine inlet air temperature is established using an electric heater controlled by temperature control instrumentation [24].

The cetane number and the emissions of the mixtures during the cetane number measuring are published in [15]. The goal of this measurement was to compare different fuels and blends, so the pre-injection angle and the compression ratio were calibrated for the reference diesel oil. For diesel oil, we used 13 degrees as pre-injection angle, and applied the compression ratio belonging to the corresponding 13 degrees of ignition delay. To assure comparability, these settings were not modified for RSO and the blends; just the fuel consumption was corrected to 13 ml/min.

THE INDICATING SYSTEM AND EMISSION MEASURING SYSTEM

We could investigate 3 channels in our measurement: The electric signal of the magnetostrictive pickup, piezo crystal (Type: AVL 6 QP 500e Nr.: 422) (Fig. 1 and 2) and the injector pintle transducer get to SMETech COMBI measurement system.

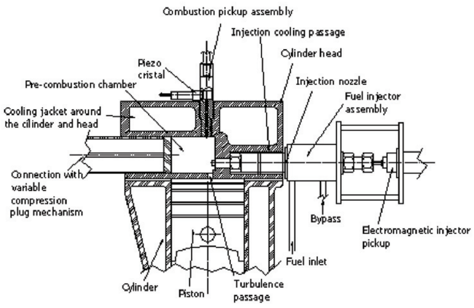

Fig. 1: *CFR F-5 Diesel combustion chamber assembly.*

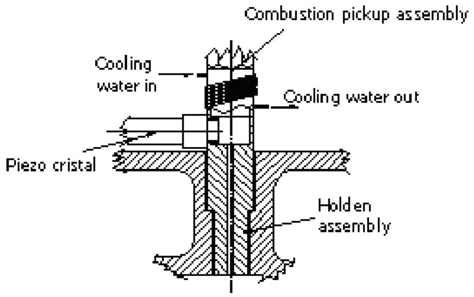

Fig. 2: *The installed piezo crystal in the pre-combustion chamber.*

For the interest of accuracy of the measurement is started by the encoder on crank axis (1024 signal/round). Our results are saved in ASCII code. The indicating system can be seen in the Fig. 3.

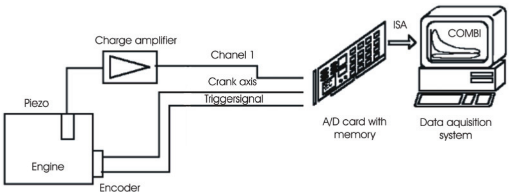

Fig. 3: *The structure of indicating system.*

The emissions were measured by Horiba Mexa-8120 F exhaust gas analyser. The measured emission parameters were NO/NO_x (by CLA-53, H CLD system), CO/CO_2 (by AIA-23 NDIR principled system), THC (by FIA-22 H-FID principled system) and smoke emission were measured by AVL 415 Variable Sampling Smoke Meter.

According the geometrical the pressure data the program determines the whole realised heat during combustion, namely the gross heat release, and the heat volume of released heat by combustion, namely the net heat release.

Programming in LabVIEW makes the averaging of every data deriving from the 99 cycles of the measurement, possible which facilitates the accuracy of calculations to a big extent. The received pressure signals gets distorted, because of the noise superponed at the sign during the measurement a low pass filter was applied for correcting it.

For the calculations it is necessary to know the all-time volume, which can be counted from the geometrical data of the engine according to the compression ratio (ε) respectively.

For setting the model, knowledge of change of pressures and displacement volumes belonging to the crank angle are needed which can be counted by numerical derivation.

Knowledge of given characteristics (c_p specific heat, R gas invariant, κ_φ isentropic index) is necessary for describing thermodynamically processes passing off at the engine. For determining all these characteristics, timely change of the constitution of the mixture burning or after the combustion respectively has to be known which can be counted with the help of equilibrium equations or reaction kinetics respectively. For this scope a dissociation model was applied [1]. The temperature belonging to the crank angle of the given crankshaft can be determined by iteration.

The part of velocity of heat release which is realized at the combustion period is called net heat release which can be counted with the help of the one zone model of Birgman [9]:

$$\frac{\mathrm{d}Q_{n,h,\varphi}}{\mathrm{d}\varphi} = \frac{1}{\kappa_\varphi - 1}\left(V_\varphi \frac{\mathrm{d}p_\varphi}{\mathrm{d}\varphi} + \kappa_\varphi p_\varphi \frac{\mathrm{d}V_\varphi}{\mathrm{d}\varphi}\right).$$

The gross heat release law, which is the whole amount of heat arising during combustion (gross heat release), is calculated as the sum of heat released by combustion of the fuel and the heat transfer to the wall:

$$Q_{g,h,\varphi} = Q_{n,h,\varphi} + Q_{wall,\varphi}.$$

The integral value of the gross heat release and the heat transfer to the wall has to be determined according to this equation for further calculation.

The difference between the temperature of the medium in the cylinder and the cylinder wall results in heat transfer. At the given crank angle the transmitted heat to the wall:

$$\mathrm{d}Q_{wall,\varphi} = \alpha_{sum,\varphi} A_{sum,\varphi}(T_{g,\varphi} - T_{A,\varphi})\mathrm{d}\tau_\varphi.$$

$A_{sum,\varphi}$ means the whole wall surface of the cylinder volume at the given crank angle, $T_{g,\varphi}$ means the average temperature of the medium, $T_{A,\varphi}$ is the average temperature of $A_{sum,\varphi}$ wall surface, $\alpha_{sum,\varphi}$ means the momentary heat transfer factor at the equation.

A part of the heat is transmitted to the wall convectively during the working process so loss deriving from gas and flame radiation will not be taken into consideration during our calculations.

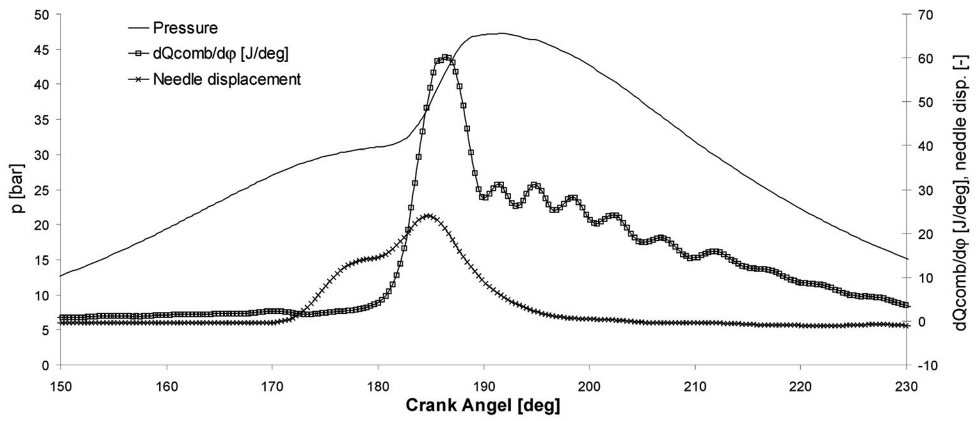

Fig. 4: *Pressure the displacement of injection needle, and heat realise rule as function of crank shaft angle [16].*

For defining the convective heat transfer factor the equation of Elser is applied [8].

Having defined the derivative of combustion, according to the above the function of combustion law is generated. Following all of these steps, in case of gas oil fuel the following graph appears (Fig. 4) which shows the function describing the pressure, the combustion law and the shift of the injection needle displacement as the function of crank angle.

MEASURED ALCOHOLS

2-propanol (isopropanol) is the lowest secondary alcohol.

Butanol is a higher alcohol with four carbon atomic nucleus. It has typical smell; it is a clear liquid. It has a high octane number, it could reach 107 RON [23]. The Butanol is also considered as a potential bio fuel. Butanol at 85 percent strength can be used in cars without any change to the engine. Butanol can be produced by fermentation of biomass by bacteria.

The higher alcohols can be produced by biological degradation, with fermentation (for example butanol), or by indirect hidradization from CO and H_2 in synthetic way with carbon-hydrogen distillation. In the Table 1 the relevant parameters of higher alcohols, rape seed oil and diesel oil are summarized.

Butanol and 2-propanol was chosen for the investigations based on economical considerations.

MEASURING

During the Cetane number rating the fuel flow rate (13 millilitres per minute) and the time of fuel injection (13 crank angle degrees before top dead centre) are constant. The ignition delay is 13 crank angle degrees which means combustion occurs 13 degrees after injection of fuel into the combustion chamber). During the measurement of blends, the consumption remained 13 ml/minute, but due to different viscosity, evaporation properties and cetane number there were changes in the pre-injection angle and in the ignition delay.

RESULTS AND DISCUSSION

Fig. 5 shows the pressure change characteristics of rape seed oil and 1-butanol blends, and also diesel oil for comparison. The Fig. 6 shows the pressure change characteristics of rape seed oil and 2-propanol blends, and of diesel oil, for comparison.

Fig. 7 shows the heat release rules of diesel oil, RSO and 1-botanol blends; while Fig. 8 shows the same for diesel oil, RSO and 2-propanol blends. It's clearly visible that for diesel oil, heat liberation occurs at the upper dead point - since the cetane rating unit was calibrated for this specific fuel. In the

Table 1: *The physical parameters of the used alcohols.* ***The results depends on year, hybrid ect.*

	2-propanol	1-butanol	Diesel oil	Rape seed oil*
Density [g/cm3]	0.785	0.8098	0.820 – 0.845	0.92
Molar mass [g/mol]	60.1	74.1	204	881
Melting point [°C]	-88.5	-89.3	-30 – -18	-5 – +5
Boiling point [°C]	82.4	117.7	282 – 338	> 350
Flash point [°C]	11.7	29	> 55	∼270
LHV [MJ/kg]	30	32	44	37
Self-ignition temp [°C]	456	345	254 – 285	∼350

other cases, heat liberation starts later. Alcohol increases the speed of heat liberation, but also shifts the beginning of the combustion ahead, as an effect of the low cetane number. Note, that the curves of the 20% blends are below the RSO curve in the beginning, their increment starts later. In the kinetic phase, the heat deliberation is more intense, higher $dQ/d\varphi$ belongs to the same change (11 degrees) in the main axis angle. No difference can be seen between the two alcohols (see Fig. 9). The diffuse phase means prolonged combustion in all cases, which is highly similar to the combustion of the RSO. This shows that by that time all alcohol has burnt out from the blends, so the characteristics of the heat release is the same for all.

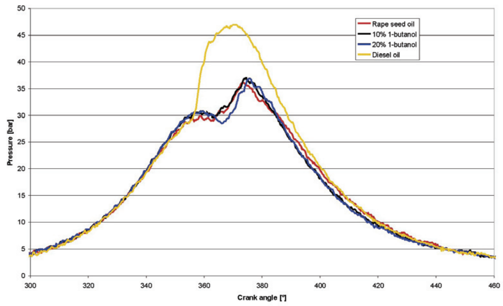

Fig. 5: *Measured pressure in case of rape seed oil–1-butanol mixtures and diesel oil.*

Figures 5 and 6 indicate that when operated with diesel oil, the pressure drastically, steeply increases at 360°. The reason of that is: due to cetane ranking unit settings, combustion starts at the upper dead point.

In the other cases, due to the different properties of the fuel, combustion does not start at the upper dead point, but only afterwards (the pre-injection changed during the measurement, the engine was configured for diesel oil).

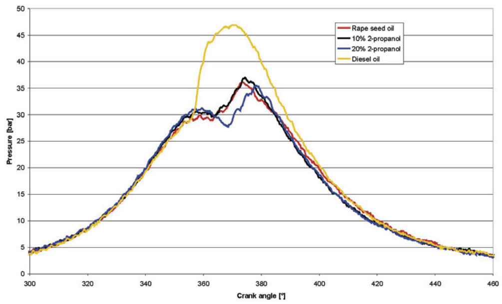

Fig. 6: *Measured pressure in case of rape seed oil–2-propanol mixtures and diesel oil.*

The pressure increment clearly indicates that in case of pure RSO the pressure starts rising earlier. That is caused by the evaporation of alcohol which cools the combustion field, increases the ignition delay, and decreases the flame propagation speed and the cetane number. It can be also observed that the peak pressure is positioned later. This can also be explained by the evaporation of alcohol.

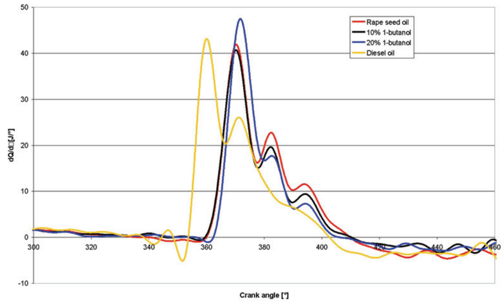

Fig. 7: *Measured heat release rule in case of rape seed oil–1-butanol mixtures and diesel oil.*

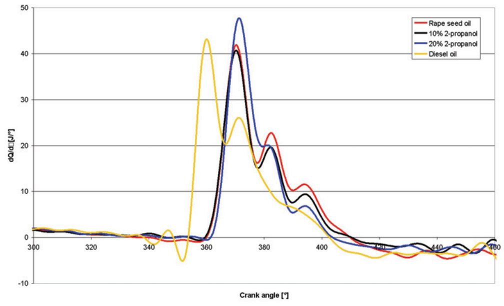

Fig. 8: *Measured heat release rule in case of rape seed oil–2-propanol mixtures and diesel oil.*

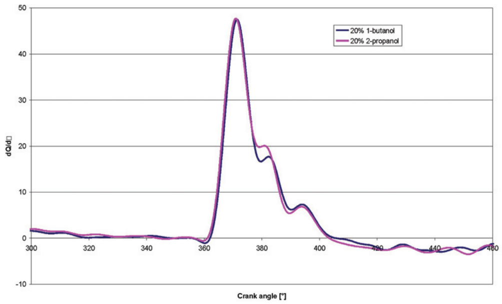

Fig. 9: *Measured heat release rule in case of rape seed oil– 20% 2-propanol and 20% 1-butanol mixtures.*

From the point of view of NO_x formation, the length of the combustion curve and the proportion of kinetic and diffuse phases are important.

Fig. 10 shows the NO_x emission of different fuels. The figure shows that adding butanol increases the amount of NO_x, while adding propanol decreases it. The reasons can be the followings (their exact determination is subject to future work): the kinetic phase is more intense in case of propanol; the speed of heat production is higher, resulting in higher average temperature, which is beneficial for NO_x formation. In case of butanol, the kinetic phase is prolonged, and this has a reduction effect on NO_x formation. It also needs to be taken into account that even though the fuel consumption was 13 ml/minute throughout the measurement, the calorific value so the introduced heat amount was the highest at rape seed oil, and decreased continuously with higher alcohol content.

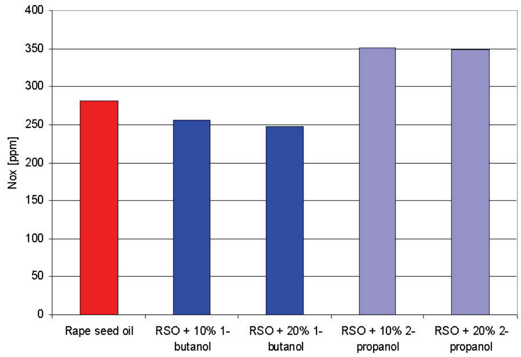

Fig. 10: *Measured* NO_x*-emission in case of rape seed oil and alcohol mixtures.*

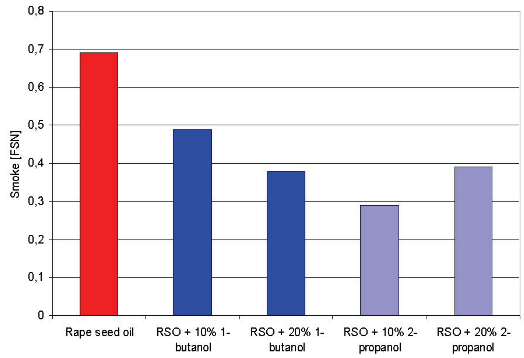

Fig. 11: *Measured Smoke-emission in case of rape seed oil and alcohol mixtures.*

Fig. 11 depicts the smoke emission. Observations show that the rape seed oil causes more smoke emission then the blends (alcohol burns with nearly smoke-free flame). The process of smoke emission can be departed into two phases: smoke formation and burnout. In case of propanol, higher alcohol content results higher smoke emission. This can also be explained by the temperature drop caused by the evaporation of alcohol; and by the fact that in case of butanol the prolonged kinetic phase gives time for the generated smoke to burn out. In case of 10% 2-propanol, part of the smoke is able to burn out in the diffuse phase after a fast kinetic phase; while in case of 20% 2-butanol the temperature may drop so much that it's not in favour of the smoke burnout.

Fig. 12 summarizes the insufficient unburned hidrocarbon emission of rape seed oil and rape seed oil-alcohol blends. Results show that in cetane ranking unit (setted for diesel oil), alcohol increases the THC emission, and the reactions get frozen due to the prolonged combustion. This can also be caused by the decreased combustion temperature. At 20% alcohol content there is no significant difference in the measured THC emission of the two alcohol types.

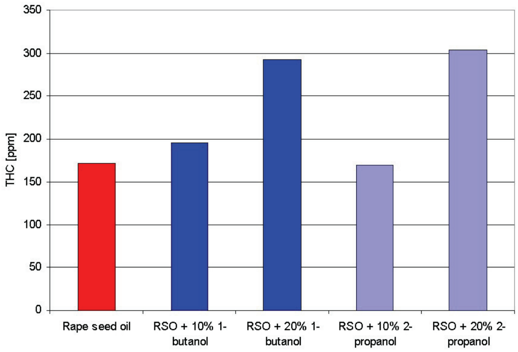

Fig. 12: *Measured THC-emission in case of rape seed oil and alcohol mixtures.*

Fig. 13 shows the measured CO emission. Results indicate that alcohol increases the CO emission. The rationale behind can be, once again the decreasing combustion temperature (reactions get frozen). The observation that at higher alcohol content the amount of CO in the smoke increases also confirms this. It's also visible that the effect of the alcohol type on the amount of emitted CO is negligible.

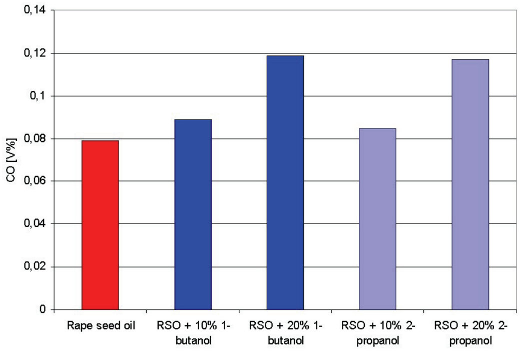

Fig. 13: *Measured CO-emission in case of rape seed oil and alcohol mixtures.*

CONCLUSIONS

Based on the measurement, it can be concluded that rape seed oil and rape seed oil-alcohol blends can also be combusted in cetane ranking unit enabled engines calibrated for diesel oil. Measurements show that alcohol decreases the smoke emission of rape seed oil, but blending rape seed oil with 20% alcohol significantly increases THC and CO emission. NO_x emission increases in case of 2-propanol and decreases in case of 1-butanol.

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