Characteristics of a tractor engine using mineral and biodiesel fuels blended with rapeseed oil

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ABSTRACT: One of the most unfavourable characteristics of crude vegetable oil when used as the fuel is the high viscosity. To improve this weakness, oil can be blended with mineral diesel or biodiesel fuels. This study was designed to evaluate how the use of mineral diesel or biodiesel blend with cold pressed rapeseed (*Brassica napus*) oil affects the engine power, torque and fuel consumption. A tractor equipped with direct injection, water cooling system and three-cylinder diesel engine was used for the experiment. Fuels used were standard diesel fuel (diesel), rapeseed oil methyl ester – biodiesel (B100) and their mixtures with 10, 30 and 50 vol. % of cold pressed rapeseed oil (RO). Increased portion of RO in diesel fuel blends had almost no effect on the torque measured on the tractor PTO shaft; it however decreased the maximal power. Fuel blends with B100 and rising RO content (up to 50%) gave a positive correlation with maximal torque and power. By increasing the portion of RO from 0 to 50%, the minimal specific fuel consumption increased by 6.65% with diesel and decreased by 2.98% with B100 based fuel.
Key words: diesel engine power, torque, fuel consumption

Características de um motor de trator alimentado com combustíveis mineral e biodisel misturados com óleo de colza

RESUMO: Uma das características mais desfavoráveis dos óleos vegetais crus usados como combustível é a alta viscosidade. Para melhorar este ponto fraco, o óleo pode ser misturado com diesel mineral ou biodiesel. Este estudo foi desenvolvido para avaliar como o uso de diesel mineral ou biodiesel misturado a oleo de colza (*Brassica napus*) extraído por pressão a frio afeta a potência do motor, o torque e o consumo de combustível, empregando um trator equipado com injeção direta, sistema de refrigeração de água e um motor de três cilindros. Os combustíveis utilizados foram o diesel padrão (diesel), éster metílico de óleo de sementes de colza – biodiesel (B100) e suas misturas com 10, 30 e 50 % vol. de óleo de semente de colza pressionado a frio (RO). Maiores proporções de RO nas misturas de diesel praticamente não tiveram efeito sobre o torque medido na tomada de força do trator; porém diminuíram a potência máxima. Misturas com B100 e conteúdos de RO até 50% apresentaram correlações positivas com torque máximo e com a potência. Aumentando a proporção de RO de 0 a 50%, o consumo mínimo específico aumentou 6.6% com diesel e decresceu 3% com combustível baseado em B100.
Palavras-chave: potência motor diesel, torque, consumo de combustível

Introduction

Today the world is facing two challenges, one is the energy (fuel) crisis and the other one is environmental degradation, especially in the form of air pollution and consequent climate change. Use of biomass as an energy source can contribute towards tackling this environmental problem. Biomass can be used for heat production, electricity generation or production of various types of liquid fuels (Raffiq and Ahamed, 2005; Ripoli et al., 2000). Vegetable oils can be used as a substitute for light oil. The most unfavourable characteristics of pure vegetable oil are high viscosity and consequently high flow resistance which weakens atomisation in the combustion chamber (Nwafor, 2004; Nwafor and Rice, 1996; Recep et al., 2001). This can be improved by the process of oil transesterification to obtain the fatty acid methyl ester – biodiesel, which can be used in usual diesel engines (Agarwal et al., 2008; Kegl, 2008; Ramadhas et al., 2004). The second possibility is to preheat vegetable oil to reduce viscosity down to a level comparable with the viscosity of mineral (fossil) diesel fuel (Agarwal and Agarwal, 2007; Aurore et al., 2003; Bari et al., 2002; Nwafor, 2004). There is also a possibility to blend vegetable oils with mineral diesel or biodiesel fuel (Huzayyin et al., 2004; Nwafor and Rice, 1996; Rakopoulos et al., 2006). Blends of mineral diesel fuel and 20% - 50% of vegetable oil can be used in diesel engines (Forson et al., 2004; Pramanik, 2003). Long-term use of such blends is, however, questionable because it gradually causes carbon deposits on vital engine parts (Labeckas and Slavinskas, 2006; Togashi and Kamide, 1999). Lower percentage, up to 20% of treated (degummed and filtered) vegetable oil, especially rapeseed oil in blend, can be used as fuel for diesel engines without long-term durability concerns (McDonnell et al., 2000).

This research was designed to evaluate whether and in which way the use of mineral diesel or biodiesel fuel blended with cold pressed rapeseed (*Brassica napus*) oil affects the tractor engine power, torque and fuel consumption.

Material and Methods

Engine tests using fuel blends were performed on the tractor Agromehanika AGT 835 equipped with direct injection, water cooled, three-cylinder diesel engine. Its mechanical transmission has six gears for forward and three gears for reverse drive. For the connection of tools, the tractor is equipped with the standard three-point linkage and power take off shaft (PTO) with rated frequencies of 540 and 1,000 rpm. The engine characteristics are given in Table 1.

The tractor engine was loaded through the PTO using the HD Andersen hydraulic-brake dynamometer. Torque and rotational frequency were measured on the PTO using a standard HBM T 30 FN probe, which was connected through a HBM MD, Spider 8 excitation and signal conditioning system to a PC and treated with HBM Catman software. The measuring frequency was 10 Hz (ten records per second). The measured values of torque, frequency and calculated values of power at full load were recorded. Fuel consumption was established by measuring the time in which a predefined volume of fuel was consumed. A schematic view of test system is shown in Figure 1. Gear ratio between the main shaft of the engine and the tractor PTO is 4.438, hence at rated engine frequency of 3000 rpm the PTO rotational frequency is 676 rpm.

Fuels used in the experiment were of two basic types: standard diesel fuel (diesel) and rapeseed oil methyl ester – biodiesel (B100). They were mixed with 10, 30 and 50 vol. % of cold pressed rapeseed oil (RO). The analysis of B100 and RO was made at an accredited laboratory in accordance to standard test methods. Properties of the diesel were submitted by the local distributor. Some physical and chemical specifications of the used fuels are summarized in Table 2 and Table 3. During the tests, the fuel temperature was 20°C. The outside air temperature was also 20°C.

Prior to the measurements, the engine was left running for 1 h to warm up all parts and liquids to the working temperature. At the same time and before each measurement for a specific fuel, the whole system (engine with PTO turned on, measuring probe and hydraulic brake set on torque 0) was running for 10 min at full throttle. Every measurement of torque and rotational frequency on PTO at certain load setting and at full throttle

Table 1 – Technical data of the engine.

Make	LOMBARDINI	Compression ratio	22:1
Type	LDW1503	Rated frequency	3,000 rpm
Cylinders	3	Rated power	26.4 kW (ISO 1885)
Displacement	1551 cm^3	Rated torque	84.5 Nm
Bore	88 mm	Max. torque	95.4 Nm at 2100 rpm
Stroke	85 mm	Min. spec. fuel consumption	268 g kWh^{-1} at 2400 rpm

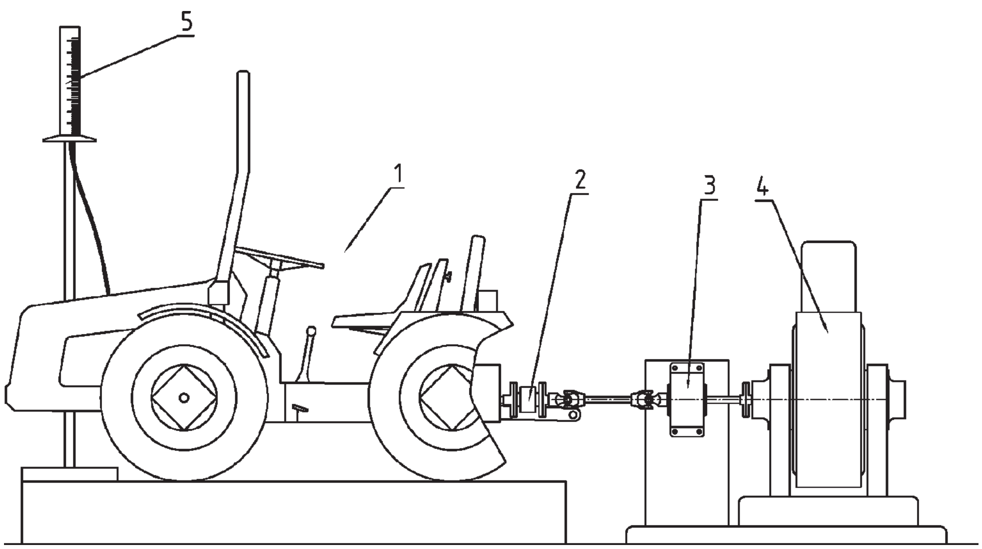

Figure 1 – Schematic view of the test arrangement (1. tractor, 2. torque/frequency measuring probe, 3. multiplication gearbox, 4. hydraulic measuring brake, 5. graduated burette).

Table 2 – Some properties of the basic fuels.

Fuel	Diesel fuel	Biodiesel	Cold pressed rapeseed oil
Mark	diesel	B100	RO
Density ρf [kg m^{-3}] (ISO 12185)	835.00	885.20	913.80
Gross heating value Hi [MJ kg^{-1}] (DIN 51900)	45.90	39.76	40.03
Kinematic viscosity ν [mm^2 s^{-1}] at 40°C (ISO 3104)	2.90	5.05	43.86
Water content [mg kg^{-1}] (ISO 12937)	80	520	480
Flash point [°C] (ISO 2719)	60	150	198
Relative difference of gross heating value in comparison with diesel fuel [%]		-13.39 %	-12.79 %

Table 3 – Values of densities and heating values for blended fuels, calculated in relation to basic fuel values and mixture rates.

Fuel blends						
Mark	Diesel-RO10	Diesel -RO30	Diesel -RO50	B100-RO10	B100-RO30	B100-RO50
Blend composition [vol. %]	90 diesel, 10 RO	70 diesel, 30 RO	50 diesel, 50 RO	90 B100, 10 RO	70 B100, 30 RO	50 B100, 50 RO
Density ρf [kg m^{-3}]	842.88	858.64	874.40	888.06	893.78	899.50
Gross heating value Hi [MJ kg^{-1}]	45.31	44.14	42.97	39.78	39.84	39.89

lasted for two minutes. During this period, the time required for the consumption of 100 mL of fuel was also recorded. The first measurement was carried out at load set zero; the only load was the friction between moving parts. For every subsequent measurement, the load on the hydraulic brake was increased in order to decrease the rotational frequency of the PTO for about 50 – 60 rpm. Each measurement again lasted 2 min. All engine settings (throttle, cooling...) stayed unchanged during the whole experiment for each particular fuel type. Using this method at least eight measurements were performed for each fuel type, gradually reducing down to about 280 rpm of the PTO. When the fuel was changed, all previous fuel was removed from pipelines and filter system. The system was filled with new fuel type and the ventilation pipe was left open for about two litres of fuel to be passed through it. After 10 min of full throttle engine running the next measurement started as already described.

From the recorded values of PTO torque, rotational frequency and time needed for 100 mL of fuel to be consumed, values of PTO power, engine rotational frequency, specific fuel consumption and efficiency were calculated. At this point is to be noted that the measurements of torque and power were carried out on a PTO and not on the engine main shaft or a flywheel. It is therefore normal that these values differ from the engine catalogue values.

Results and Discussion

Power

The power of the fully loaded engine measured on the PTO and using a specific portion of RO in blends with diesel and B100,when diesel and its blends with RO were used showed only slight differences in measured power up to 2,500 rpm (Figure 2, A and B). On some engine rotational frequency intervals the power was even higher using 10% RO in the blend. At high rotational frequencies, differences increased. The same maximal power was observed with diesel and blend with 10% RO while blends with higher portion of RO resulted lower power. Forson at al. (2004) added jatropha (*Jatropha curcas*) oil to diesel fuel and observed an increased engine power and torque, and a decreased specific fuel consumption. Maximal differences compared to neat diesel fuel were only achieved at 2.6% jatropha oil in the fuel blend. Huzayyin et al. (2004) observed slightly lower power by all rotational frequencies, using 20% jojoba (*Simmondsia chinensis*) oil in the blend. However, the slightly higher values of engine power using the same fuel blend were observed at full engine loads and high speed conditions. B100 based blends with RO, however, showed larger differences of power on the whole rotational frequency interval. B100 blends with higher proportion of RO gave higher powers on average.

Variations of maximal engine power values in relation to fuel composition (Figure 3) indicate that the use of diesel based fuel results in a decrease of the maximal available engine power when higher proportions of RO are used in the blend. Using the blend with 50% of RO resulted in 4.4% decrease in maximal power compared with pure diesel fuel. On the other hand, the use of the B100 fuel blends had opposite results. The use of pure B100 resulted in 5.5% lower power than when 50% of RO blend was used. Maximal power using diesel fuel was 4.7% higher than when B100 was used. Almost the same difference was observed when 10% of RO was used in fuel blends. With the increasing proportion of RO, the B100 blends result in higher maximal power. The fuel blend B100-RO50 gives 5.5% higher maximal power than the blend diesel-RO50 and also higher than neat diesel fuel. Vegetable oil based fuels can give higher maximal engine power compared to mineral diesel fuel. Aurore et al. (2003) reported that for a commercial road vehicle engine the seed oil fuel produced around 12% higher maximal power than diesel fuel. With the increasing proportion of RO the maximal power decreases while at the same time for B100 based fuel it increases (Figure 3). The regression is significant at the 90% confidence level for both basic fuel types. Statistical analyses and significance of linear regressions are presented in Tables 4 and 5.

Single portion of RO in diesel fuel blends had almost no impact on the measured torque on tractor PTO. Only the blend with 50% of RO gave lower values of torque at more than 2,600 rpm, (Figure 4A). In Figure 4B a different relation can be seen for measured torque on PTO values when using B100 fuel blends. Pure B100 fuel gave the lowest torque, but, at the same time, the higher the portion of RO in fuel blends was, the higher was the torque, up to 2,700 rpm. This principle was also valid for maximal torque. At rotational frequencies above 2,900 rpm, only B100-RO50 fuel blend gave lower values of torque. B100 fuel blends gave the maximal torque at lower rotational frequencies of engine in comparison to the pure B100 fuel.

Different proportions of RO in diesel fuel blends had no influence on maximal torque. B100 fuel blends with the RO content up to 50%, on the other hand, gave positive correlation with maximal torque. This was also confirmed using the linear regression analysis of maximal torque vs. RO content in fuel blend (Figure 5). The re-

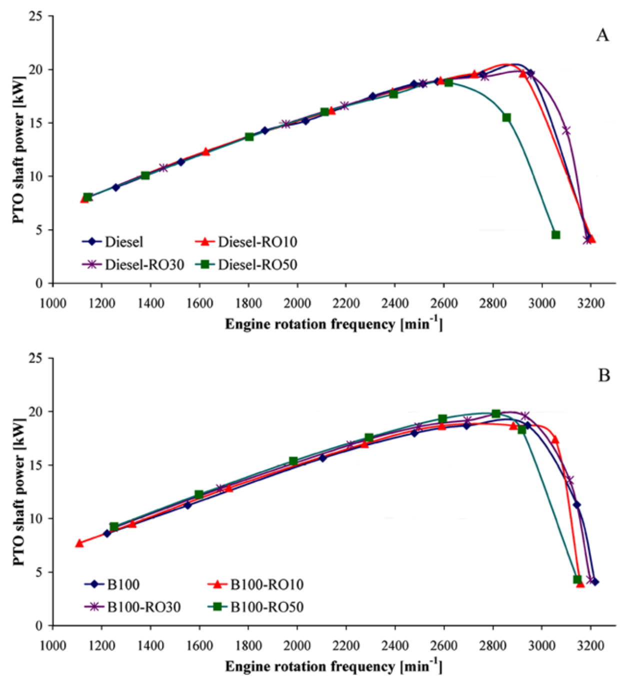

Figure 2 – Power on PTO using blended mineral diesel (A) fuel at full load and blended B100 fuel (B) at full load.

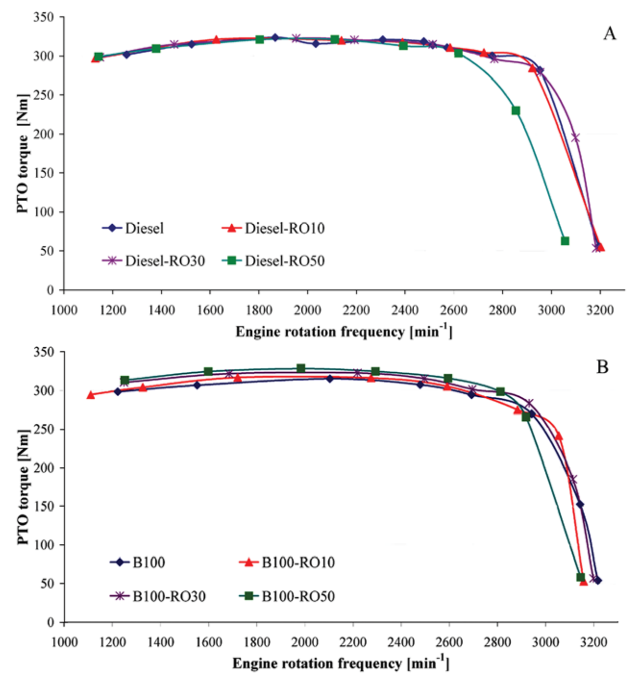

Figure 4 – Torque on PTO using diesel blended fuel (A) at full load and B100 blended fuel (B) at full load.

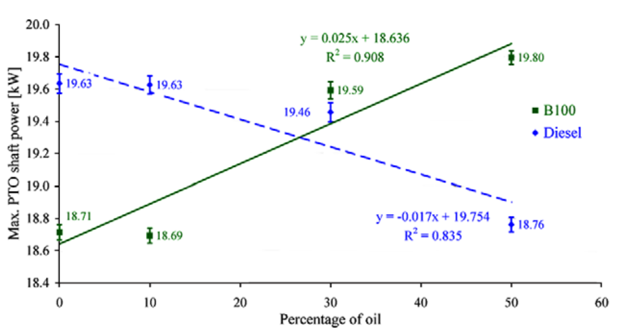

Figure 3 – Average values with 95% confidence limits and linear regression of maximal PTO power vs. oil content in fuel blends.

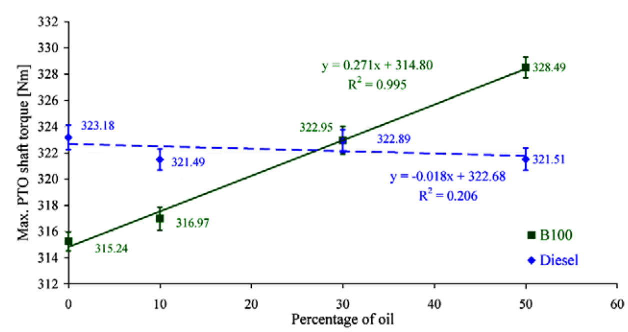

Figure 5 – Average values with 95% confidence limits and linear regression of maximal PTO torque vs. Rapeseed oil content in fuel blends.

Table 4 – Regression analyses between the observed characteristics and the quantity of rapeseed oil in blends with diesel basic fuel (✓ - significant, ✗ - not significant).

Observed characteristics		Estimate	*p* value	R^2	Correlation coefficient	Significance at 95% confidence level	Significance at 90% confidence level
P_{max}	Intercept	19.754	0	83.534	-0.914	✗	✓
	Slope	-0.017	0.086				
T_{max}	Intercept	322.679	0	20.568	-0.454	✗	✗
	Slope	-0.018	0.547				
q_{min}	Intercept	328.552	0	88.367	0.940	✗	✓
	Slope	0.412	0.060				

Table 5 – Regression analyses between the observed characteristics and the quantity of rapeseed oil in blends with B100 basic fuel (✓ - significant, ✗ - not significant).

Observed characteristics		Estimate	*p* value	R^2	Correlation coefficient	Significance at 95% confidence level	Significance at 90% confidence level
P_{max}	Intercept	18.636	0	90.822	0.953	✓	✓
	Slope	0.025	0.047				
T_{max}	Intercept	314.802	0	99.539	0.998	✓	✓
	Slope	0.272	0.002				
q_{min}	Intercept	361.113	0	92.44	-0.9610	✓	✓
	Slope	-0.195	0.039				

gression coefficient is negative, however, this behaviour is not significant (Table 4) since the increase in the content of RO in the B100 fuel blend had a positive impact on the maximal torque with a significant correlation (Table 5). This can be explained by the higher amount of injected fuel as a consequence of earlier injection nozzle opening and higher fuel pressure in the nozzle due to different viscosity and compressibility of the fuel blends (B100 and RO) rich on vegetable oil.

Using B100 and its blends, the engine had a higher minimal specific consumption compared with diesel blends (Figure 6). This was expected because of the lower energy content of bio fuels used. The difference between heating values of diesel and B100 based blends, on the other hand, decreased with higher percentage of RO in each. An inverted trend was also observed between diesel and B100 fuel blends. With the increase in the proportion of RO from 0 to 50%, the minimal specific fuel consumption increased 6.65% for diesel and decreased 2.98% for B100 based fuel. The reason for higher fuel consumption at increasing RO contents in diesel fuel blends can be explained by the lower energy values of this fuel type. Diesel-RO50 fuel blend has a 6.39% lower gross heating value when compared with pure diesel fuel. At the same time, this represents almost the same value as the increase of fuel consumption.

All fuel blends with B100 base have almost the same gross heating value, which means that the decrease of minimal specific fuel consumption should come from a different source. Nwafor and Rice (1996) established no difference of specific fuel consumption with different RO blends with diesel fuel except with neat RO. Forson at al. (2004) reported on slightly reduced specific fuel consumption for diesel fuel blends with increasing proportion of jatropha oil.

The increase of the RO proportion in fuel blends with B100 lead to decreases of minimal specific fuel consumption. This is not the result of a different heating value, because B100 and all its blends have almost the same heating value. Changes in minimal specific fuel consumption are mainly the result of different fuel energy conversion efficiencies inside the treated diesel engine (Figure 7). Higher efficiencies were established by Nwafor and Rice (1996) for neat RO and 25% diesel – 75% RO fuel blend and Rakopoulos et al. (2006) for about 2% at medium engine load with diesel fuel blends containing 10% and 20% of vegetable oils of different origin. Togashi and Kamide (1999) and also Labeckas and Slavinskas (2006) reported higher efficiencies with RO fuel in comparison with diesel fuel at moderate and higher engine load.

The engine efficiency at minimal B100-RO50 fuel blend consumption is 2.75% higher than that pure B100. At the same time, the difference between minimal specific consumption for the same fuels is 2.98%, which is almost the same value. Relative differences of minimal specific fuel consumption, gross heating value and efficiency between B100 and diesel base fuels, and their blends with RO at engine minimal specific fuel consumption working conditions are presented in Figure 8. Single columns present the relative values for which the

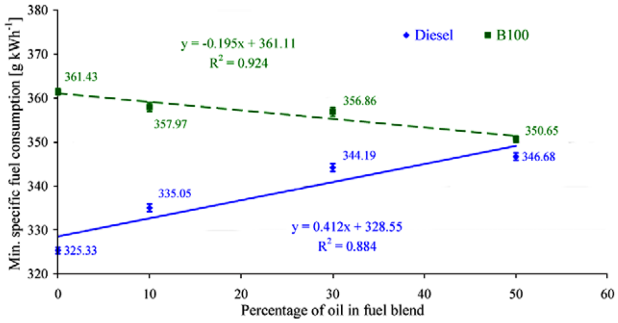

Figure 6 – Average values with 95% confidence limits and linear regression of minimal specific fuel consumption vs. oil content in fuel blends.

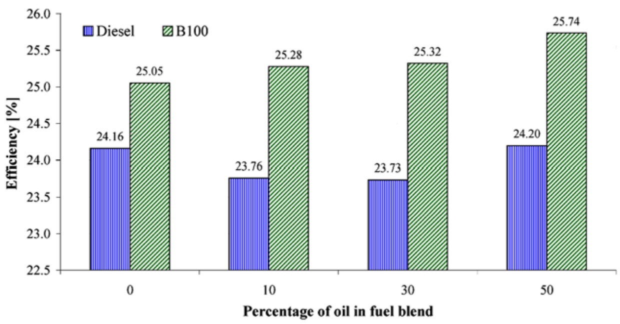

Figure 7 – Efficiencies of different fuel energy conversion at engine full load and minimal specific fuel consumption working regime.

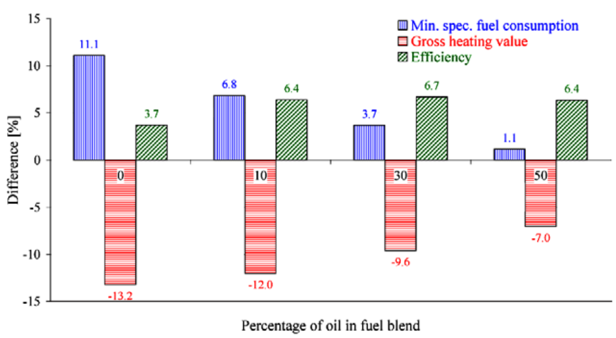

Figure 8 – Relative difference of minimal specific fuel consumption, gross heating value and efficiency of energy conversion for B100 basic fuel and its 10%, 30% and 50% rapeseed oil blends in relation to diesel.

observed variables of the B100 fuel blends are higher (or lower) in relation to diesel. The comparison between pure B100 and diesel fuels shows that minimal specific consumption of B100 fuel is higher for 11%, the efficiency for 3.7%, but the gross heating value is 13.2% lower than that of diesel. B100-RO10 blend showed 6.8% higher minimal specific consumption, 6.4% higher efficiency and 12.0% lower heating value in comparison with diesel-RO10 blend and so on for -RO30 and -RO50 blends.

Conclusions

The use of blends of diesel and increased percentage of RO resulted in a slight loss of maximal engine power and torque and an increase in specific fuel consumption. Compared to pure diesel fuel, the engine using pure B100 showed decreased maximal power and torque and higher fuel consumption. However, when blends of B100 fuel with RO are used, an improvement was observed in the performance of the diesel engine. These fuel blends also do not require any engine conversion such as those necessary for the use of pure RO fuel.

Acknowledgement

To the European Community Sixth Framework Programme in the scope of the Civitas II Mobilis project.

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Received January 23, 2009
Accepted June 18, 2010