CZECH
UNIVERSITY
OF LIFE SCIENCES PRAGUE

EFFECT OF DIESEL FUEL–COCONUT OIL–BUTANOL BLENDS ON OPERATIONAL PARAMETERS OF DIESEL ENGINE

Faculty of Engineering

Jakub Čedík[1,*], Martin Pexa[1], Michal Holúbek[1], Zdeněk Aleš[1], Radek Pražan[2] and Peter Kuchar[3]

[1]Czech University of Life Sciences, Faculty of Engineering
[2]Research Institute of Agriculture Engineering
[3]Slovak University of Agriculture in Nitra, Faculty of Engineering

Abstract

Global concentration of greenhouse gasses in the atmosphere is increasing as well as the emissions of harmful pollutants. Utilization of liquid biofuels in combustion engines helps to reduce these negative effects. For diesel engines the most used alternative fuels are based on vegetable oils. Blending neat vegetable oils with diesel and/or alcohol fuels is a simple way to make it suitable for diesel engines. In the study a coconut oil was used in the ternary fuel blends with diesel and butanol. The coconut oil is potentially usable source of renewable energy, especially in Pacific, where it is a local product. Diesel fuel–coconut oil–butanol fuel blends were used in concentrations of 70%–20%–10% and 60%–20%–20%, 100% diesel fuel was used as a reference. The effect of the fuel blends on, production of harmful emissions, engine smoke, performance parameters, fuel consumption and solid particles production was monitored during the measurement. The engine was kept at constant speed during the measurement and the load was selected at 50%, 75% and 100%. From the results it can be stated that in comparison with diesel fuel, the specific fuel consumption increased with a positive effect on reduction of engine smoke.

Introduction

Considering the globally rising energy consumption and greenhouse gasses (GHG) emissions in the agriculture sector, the utilization of renewable energy sources seems as a good alternative to fossil fuels. One of the most common energy sources in agriculture sector is the diesel engine, in which a products or side-products of the agriculture production can be used as an alternative fuel. For CI engine a fuels based on variety of edible or non-edible vegetable oils were tested as an alternative to diesel fuel [1–6].

Coconut oil is extracted from the kernel of coconut or copra (flesh from a coconut) and it is an edible vegetable oil. Its energy potential lies in the utilization in the location of its origin, such as Pacific Islands or Indonesia, where it is used for transport and electricity generation due to its relatively low local price [7,8]. Also, its economic benefits can decrease the transport costs during the coconut flesh production, however it would not drastically increase the income [9]. From the viewpoint of storability the coconut oil has a high content of saturated fat, which slows down its oxidization process and make the coconut oil resistant to acidification for up to two years [10]. The main advantage of coconut oil in comparison with other vegetable oils is its relatively high cetane number 50.3, which is approx. the same as the diesel fuel [11]. The cetane number of rapeseed oil, one of the most cultivated energy crop in Europe [12,13], is 41.6 [14], the cetane number of croton oil and oil from Jatropha curcas, which are also frequently used for energy purposes, is 40.7 and 41.8, respectively [11].

The ternary blends of vegetable oil, diesel fuel and butanol increases emissions of CO and BSFC, and decreases emissions of CO_2, brake power, engine efficiency and engine smoke in comparison with diesel fuel [15–21]. However, Atmanli et al. [22] found lower emissions of CO in comparison with diesel using diesel fuel – butanol – cotton oil fuel blend. Emissions of NO_X were found increased in some studies [15,17–19] and in other studies [16,21,22] decreased. Emissions of HC were also found increased in number of studies [16,21] and decreased in other studies [15,17,19,22] in comparison with diesel fuel.

The aim of the paper was to experimentally determine the influence of coconut oil and n-butanol in ternary blends with diesel fuel on the emissions of CO_2, NO_X, CO and HC, engine smoke, performance parameters, BSFC and production of solid particles. Butanol in the fuel blends is used to improve the fuel properties, especially the viscosity, and to increase the bio-content in the fuel.

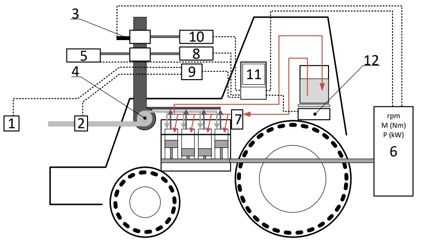

Figure 2. Measurement scheme 1 – sensor of pressure and temperature of intake air, 2 – mass air flow sensor, 3 – exhaust gas temperature sensor, 4 – turbocharger, 5 – opacimeter BrainBee OPA 100, 6 – dynamometer MAHA ZW 500, 7 – fuel pump, 8 – emission analyser BrainBee AGS 200, 9 – A/D converter LabJack U6, 10 – EEPS, 11 – PC for control and data record, 12 – Laboratory scale with external fuel tank

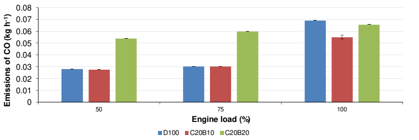

Figure 3. Emission of CO in dependence on engine load for all tested fuels

Materials and Methods

As a tested fuels the blends of diesel fuel, coconut oil and n-butanol were used. 100% diesel fuel (D100) with no bio-components was used as a reference fuel. The blends were used in concentrations of 70% diesel fuel, 20% coconut oil, 10% n-butanol (D70C20B10) and 60% diesel fuel, 20% coconut oil and 20% n-butanol (D60C20B20). Basic properties of the fuels are listed in Tab. 1.

The measurement was performed using the turbocharged CI engine Zetor 1204, mounted in the tractor Zetor Forterra 8641 (Fig. 1). The engine is in factory settings (unmodified) and the operating time of engine did not exceed 170 h.

The load of the engine was done by means of mobile dynamometer MAHA ZW 500 , connected to the tractor PTO shaft. Transmission losses have no effect on comparative measurement and therefore they were not taken into account.

Fuel consumption was measured by means of laboratory scale Vibra AJ 6200. Exhaust gas emissions were monitored by means of emission analyser BrainBee AGS 200. The engine smoke was measured by means of the opacimeter BrainBee OPA 100. Production and size distribution of solid particles, produced by engine, was monitored by means of Engine Exhaust Particle Sizer (EEPS) spectrometer model 3090 made by TSI, Inc. Mass air flow (MAF) sensor Sierra FastFlo 620S was used for monitoring of MAF. Exhaust gas temperature was measured by means thermocouple type K in the exhaust muffler.

The measurement was carried out in stabilized conditions. Rotation speed of the engine was kept constant during the measurement. Speed of the engine was set to 1950 min⁻¹, since at this engine speed the PTO shaft reaches its nominal speed, which is necessary for proper function of connected equipment. The load of the engine was selected at 50%, 75% and 100%. Engine load (in percentage) was calculated from maximum brake torque at the respective speed, reached using the reference fuel D100.

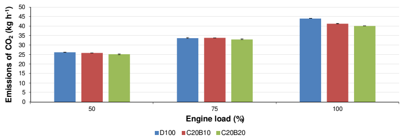

Figure 4. Emission of CO_2 in dependence on engine load for all tested fuels

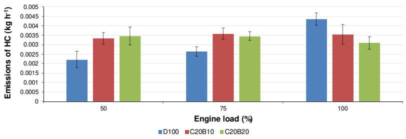

Figure 5. Emission of CO_2 in dependence on engine load for all tested fuels

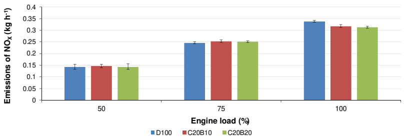

Figure 6. Emission of CO_2 in dependence on engine load for all tested fuels

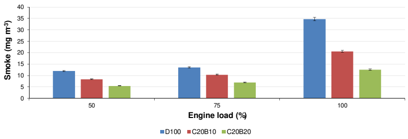

Figure 7. Emission of CO_2 in dependence on engine load for all tested fuels

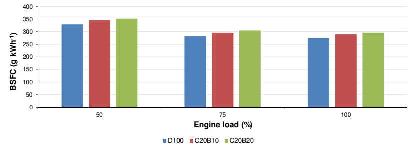

Figure 8. Emission of CO_2 in dependence on engine load for all tested fuels

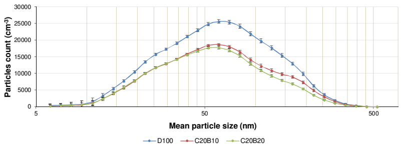

Figure 9. Emission of CO_2 in dependence on engine load for all tested fuels

Tab 1. Basic parameters of the engine of the generator

Fuel	Kinematic Viscosity at 40°C (mm^2 s^{-1})	Density at 15°C (kg m^{-3})	Cetane number	Latent heat of evaporation (kJ kg^{-1})
D100	2.722	837.5	50	250
Coconut oil	28.029	919.67 (at 40°C)	50.3	-
N-butanol	2.266	815.27	17–25	585
C20B10	3.739	852.8	-	-
C20B20	3.397	848.9	-	-

Results and Discussion

In Fig. 2 the emissions of CO for all tested fuels at all engine loads can be seen. It is evident that both of the tested fuel blends decreased production of CO at full engine load in comparison with D100. Also, the fuel blend C20B20 reached at the engine loads at 50% and 75% higher production of CO by 90.9% and 97% respectively.

In Fig. 3 the production of CO_2 at all engine loads using all tested fuels is shown. At engine loads of 50% and 75% the differences in CO_2 production are relatively small. The higher differences at full engine load may be caused by lower carbon content of fuels containing coconut oil and n-butanol and therefore their lower calorific value. Also, it is evident that with increasing proportion of n-butanol the emissions of CO_2 are decreasing. This is caused by the low cetane number of n-butanol, causing later start of combustion and therefore ineffective oxidation of CO to CO_2. Similar results concerning emissions of CO_2 and CO were reached also in other studies dealing with ternary blends of vegetable oil, diesel fuel and butanol in comparison with diesel fuel [15,16,18,19,21].

In Fig. 4 the production of the emissions of HC using all tested fuels at all tested engine loads is shown. All the differences and absolute measured values of volumetric concentrations were under the measurement accuracy.

In Fig. 5 the production of the emissions of NO_X for all tested fuels at all measured engine loads is shown. At 50% and 75% engine load the differences of blended fuels in and D100 are relatively small. At full engine load it can be observed, that the NO_X emissions are decreased with the increasing content of n-butanol in the blend. This can be explained by higher latent heat of evaporation of n-butanol. This can be also verified by the exhaust gas temperature which is decreased with increasing proportion of n-butanol at all tested engine loads. Sharon et al. [16] found similar results concerning lower emissions of NO_X and exhaust gas temperature when using used palm oil – diesel fuel – butanol blends.

In Fig. 6 the amount of produced smoke by the engine using all tested fuels at all measured engine loads can be seen. It is evident that engine smoke is significantly lower when using both of the tested fuel blends in comparison with D100. This can be explained by higher oxygen content and higher amount of light fractions in the fuel blends in comparison with D100. Researchers found lower smoke when using vegetable oil – diesel fuel – butanol blends [16,18,21] and coconut oil – diesel fuel blends [23–25] in comparison with diesel fuel.

Fuel blends also caused the decrease of maximum engine torque, which can be explained by lower calorific value of blended fuels and worsened efficiency of oxidation.

In Fig. 7 the BSFC for all tested fuels ant all measured engine loads can be seen. Concerning lower calorific value of the fuel blends in comparison with D100 and worsened efficiency of oxidation, which is evident from emissions results, the increased BSFC and mass fuel consumption can be expected. Increase of BSFC was found using vegetable oil–diesel fuel–butanol blends [15–17,19,22], coconut oil–diesel fuel blends [23–25].

The concentration of solid particles in the size range of 5.6–560 nm was decreased at all measured points using both blended fuels. In Fig. 8 the example of size distributions of solid particles for all tested fuels at 50% engine load is shown. The decrease of solid particles was caused, similarly as in the case of engine smoke, mainly by higher oxygen content and higher proportion of light fractions in the fuel blends, causing higher volatility and faster oxidation process. Also, it was found that both of the tested fuel blends tends to decrease the mean size of the solid particles.

Conclusions

From the obtained results the following conclusions were made:

- Emissions of CO and emissions of CO_2 decreased. Which, in combination with increased emissions of HC, points on worsened oxidation efficiency.
- At the full engine load the emissions of NO_X were decreased as the exhaust gas temperature was also decreased. This can be explained by the lower calorific value of the fuel blends and relatively high heat of evaporation of n-butanol.
- Engine smoke and amount of produced solid particles in the size range of 5.6–560 nm were decreased mainly due to increased oxygen content in the fuel blends in comparison with D100. Both of the tested fuel blends were found to decrease the mean size of solid particles.
- Performance parameters were decreased and BSFC was increased because of lower calorific value and worsened oxidation efficiency.

Figure 1. Tractor Zetor Forterra 8641

References

1. Mat, S.C.; Idroas, M.Y.; Hamid, M.F.; Zainal, Z.A. Performance and emissions of straight vegetable oils and its blends as a fuel in diesel engine: A review. *Renew. Sustain. Energy Rev.* **2018**, *82*, 808–823, DOI: 10.1016/j.rser.2017.09.080.
2. Jindra, P.; Kotek, M.; Mařík, J.; Vojtíšek, M. Effect of different biofuels to particulate matters production. *Agron. Res.* **2016**, *14*, 783–789.
3. Dabi, M.; Saha, U.K. Application potential of vegetable oils as alternative to diesel fuels in compression ignition engines: A review. *J. Energy Inst.* **2019**, *92*, 1710–1726, DOI: 10.1016/j.joei.2019.01.003.
4. Gui, M.M.; Lee, K.T.; Bhatia, S. Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. **2008**, 1646–1653, DOI: 10.1016/j.energy.2008.06.002.
5. Agarwal, A.K.; Dhar, A. Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine. *Renew. Energy* **2013**, *52*, 283–291, DOI: 10.1016/j.renene.2012.10.015.
6. Agarwal, A.K.; Rajamanoharan, K. Experimental investigations of performance and emissions of Karanja oil and its blends in a single cylinder agricultural diesel engine. *Fuel* **2008**, *86*, 106–112, DOI: 10.1016/j.apenergy.2008.04.008.
7. Cloin, J. Coconut Oil as a Biofuel in Pacific Islands. *Refocus* **2005**, *6*, 45–48, DOI: https://doi.org/10.1016/S1471-0846(05)70431-5.
8. How, H.G.; Teoh, Y.H.; Masjuki, H.H.; Kalam, M.A. Impact of coconut oil blends on particulate-phase PAHs and regulated emissions from a light duty diesel engine. *Energy* **2012**, *48*, 500–509, DOI: 10.1016/j.energy.2012.10.009.
9. Parry, D. Coconut Oil Biofuel in the Pacific Available online: http://large.stanford.edu/courses/2014/ph240/parry1/ (accessed on Jan 17, 2020).
10. Vara Prasad, V. Performance of 4 Stroke Diesel Engine Using Coconut Oil As Biofuel Material. *Mater. Today Proc.* **2017**, *4*, 5312–5319, DOI: 10.1016/j.matpr.2017.05.041.
11. Lujaji, F.; Bereczky, A.; Janosi, L.; Novak, C.; Mbarawa, M. Cetane number and thermal properties of vegetable oil, biodiesel, 1-butanol and diesel blends. *J. Therm. Anal. Calorim.* **2010**, *102*, 1175–1181, DOI: 10.1007/s10973-010-0733-9.
12. Viccaro, M.; Cozzi, M.; Rocchi, B.; Romano, S. Conservation agriculture to promote inland biofuel production in Italy: An economic assessment of rapeseed straight vegetable oil as a self-supply agricultural biofuel. *J. Clean. Prod.* **2019**, *217*, 153–161, DOI: 10.1016/j.jclepro.2019.01.251.
13. Jezierska-Thöle, A.; Rudnicki, R.; Kluba, M. Development of energy crops cultivation for biomass production in Poland. *Renew. Sustain. Energy Rev.* **2016**, *62*, 534–545, DOI: 10.1016/j.rser.2016.05.024.
14. Laza, T.; Bereczky, Á. Basic fuel properties of rapeseed oil-higher alcohols blends. *Fuel* **2011**, *90*, 803–810, DOI: 10.1016/j.fuel.2010.09.015.
15. Atmanli, A.; Ileri, E.; Yuksel, B.; Yilmaz, N. Extensive analyses of diesel-vegetable oil-n-butanol ternary blends in a diesel engine. *Appl. Energy* **2015**, *145*, 155–162, DOI: 10.1016/j.apenergy.2015.01.071.
16. Sharon, H.; Jai Shiva Ram, P.; Jenis Fernando, K.; Murali, S.; Muthusamy, R. Fueling a stationary direct injection diesel engine with diesel-used palm oil–butanol blends – An experimental study. *Energy Convers. Manag.* **2013**, *73*, 95–105, DOI: 10.1016/j.enconman.2013.04.027.
17. Atmanli, A.; Ileri, E.; Yüksel, B. Effects of higher ratios of n-butanol addition to diesel-vegetable oil blends on performance and exhaust emissions of a diesel engine. *J. Energy Inst.* **2015**, *88*, 209–220, DOI: 10.1016/j.joei.2014.09.008.
18. Lujaji, F.; Bereczky, A.; Mbarawa, M. Performance Evaluation of Fuel Blends Containing Croton Oil, Butanol, and Diesel in a Compression Ignition Engine. *Energy & Fuels* **2010**, *24*, 4490–4496, DOI: 10.1021/ef100456a.
19. Atmanli, A.; Ileri, E.; Yüksel, B. Experimental investigation of engine performance and exhaust emissions of a diesel engine fueled with diesel-n-butanol-vegetable oil blends. *Energy Convers. Manag.* **2014**, *81*, 312–321, DOI: 10.1016/j.enconman.2014.02.049.
20. Babu, V.M.; Murthy, M.K.; Prasad Rao, A.G. Butanol and pentanol: The promising biofuels for CI engines – A review. *Renew. Sustain. Energy Rev.* **2017**, *78*, 1068–1088, DOI: 10.1016/j.rser.2017.05.038.
21. Lujaji, F.; Kristóf, L.; Bereczky, A.; Mbarawa, M. Experimental investigation of fuel properties, engine performance, combustion and emissions of blends containing croton oil, butanol, and diesel on a CI engine. *Fuel* **2011**, *90*, 505–510, DOI: 10.1016/j.fuel.2010.10.004.
22. Atmanli, A.; Ileri, E.; Yilmaz, N. Optimization of diesel-butanol-vegetable oil blend ratios based on engine operating parameters. *Energy* **2016**, *96*, 569–580, DOI: 10.1016/j.energy.2015.12.091.
23. Machacon, H.T.C.; Matsumoto, Y.; Ohkawara, C.; Shiga, S.; Karasawa, T.; Nakamura, H. The effect of coconut oil and diesel fuel blends on diesel engine performance and exhaust emissions. *JSAE Rev.* **2001**, *22*, 349–355, DOI: 10.1016/S0389-4304(01)00111-4.
24. Machacon, H.T.C.; Shiga, S.; Karasawa, T.; Nakamura, H. Performance and emission characteristics of a diesel engine fueled with coconut oil-diesel fuel blend. *Biomass and Bioenergy* **2001**, *20*, 63–69.
25. Kalam, M.A.; Husnawan, M.; Masjuki, H.H. Exhaust emission and combustion evaluation of coconut oil-powered indirect injection diesel engine. *Renew. Energy* **2003**, *28*, 2405–2415, DOI: 10.1016/S0960-1481(03)00136-8.

Acknowledgement. Paper was created with the grant support funded by Internal Grant Agency of Czech University of Life Sciences Prague, Faculty of Engineering – IGA CULS – 2018:31190/1312/3117 and IGA CULS – 2019:31190/1312/3101

Contact

Jakub Čedík, Ph.D.
Czech University of Life Sciences Prague; Faculty of Engineering
Department for Quality and Dependability of Machines
Kamýcká 129; 165 21; Praha 6 – Suchdol; Czech Republic
Email: cedikj@tf.czu.cz
Website: www.tf.czu.cz
Phone: +420 224 383 321