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EFFECT OF USING A SOYBEAN OIL AND DIESEL FUEL MIXTURE ON THE POWER AND EXHAUST EMISSIONS OF A TRACTORS DIESEL ENGINE

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Abstract: Aim of paper is to determine the impact of the mixing of crude soybean oil in mineral diesel fuel on the performance of an internal combustion diesel engine in a tractor. Laboratory testing has determined the impact of the use of such a fuel mixture on the rated engine power and exhaust emissions (CO, CO_2, HC and NO_x). For the purposes of the test, four types of fuel were used, diesel fuel, and mixtures of diesel fuel and soybean degummed oil in concentrations of 5% (S5), 10% (S10) and 20% (S20). Power measurement revealed an increase in average engine power and torque. Hourly fuel consumption was almost the same for all types of fuel. Measurement of exhaust emissions showed an increase in CO, HC and NO_x emissions with the addition of soybean oil to diesel fuel
Keywords: engine power, fuel consumption, tractor performance, alternative fuel

INTRODUCTION

Energy is an important input for economic growth and improving the quality of life, and fossil fuels are still the main conventional source of energy. Most countries import crude oil to meet the increasing demand for energy, and in order to achieve partial independence, various alternative fuels are introduced (*Sahoo, P. K., Das, L. M., Babu, M. K. G et al., 2009*). Based on the above, biodiesel has received considerable attention considering the possibility of its use as a renewable alternative fuel and as an addition to existing petroleum–based fuels (*Barnwal, B. K., Sharma, M. P., 2004*).

Fossil diesel is formed by hundreds of different chains of carbohydrates with residual sulfur and residual crude oil, and even low–sulfur and low–aromatic fossil diesel fuels contain 20–24% aromatics (benzene, toluene, xylene, etc.) that are volatile, toxic and carcinogenic (*Tomić, M. D., Savin, L. Đ., Micić, R. D. et al., 2013*). With this, the advantage of biodiesel is that it does not contain sulfur or aromatic compounds, and the possibility of engine wear is reduced because it is characterized by good lubrication properties compared to fossil diesel and diesel fuels with a low sulfur content (*Lapuerta, M., Armas, O., Rodriguez–Fernandez, J., 2008*).

Oil fuel emissions have a harmful effect on nature. For example, an uncontrolled increase in CO_2 causes an excess of greenhouse gases which consequently results in an increase in temperature (global warming) and a decrease in temperature (global cooling) in nature. Other main harmful emissions are CO, NO_x and UHC. In addition, our energy reserves are decreasing in proportion to the growing demand for energy. (*Demirbas, A., 2007*).

Natural gas, hydrogen, vegetable oil, alcohol and biogas are some of the most important alternative fuels. The use of biofuels and alcohol (ethanol, methanol) in diesel fuels as a mixture has been intensively researched in the last few decades. The performance and exhaust emissions of diesel engines using different biodiesels have been studied by many researchers (*Canakcı, M., Van Gerpen, J., 2001; Altıparmak, D., Keskin, A., Koca, A., et al., 2007*).

The use of biodiesel does not require any engine modifications or fuel injection system modifications, with the exception of older engine designs that require replacement of gaskets and fuel injection hoses (*Fang, T., Lin, Y. C., Foong, T. M., et al., 2009*).

According to Qi, D. H., Geng, L. M., Chen, H., et al. (2009) engine performance (power, torque and fuel consumption) using biodiesel is similar to engine performance produced by fossil diesel combustion.

In addition to the mentioned advantages, the use of biodiesel also has disadvantages. According to previous research, the use of biodiesel increases the content of NO_x in combustion products (*Hazar, H., 2009; Taymaz, I., Sengil, M., 2010*). The higher content of NO_x in combustion products can be explained by the high content of oxygen in biodiesel (*Mustapić, Z., Krička, T., Stanić, Z., 2006*). Due to the unfavorable low –temperature properties of biodiesel, there are problems with starting the engine and using the diesel engine in cold weather, and due to its high hygroscopicity, it absorbs water during storage (*Tomić, M. D., Savin, L. Đ., Micić, R. D. et al., 2013*).

Emissions of HC, CO and particulate matter (PM) are reduced by using biodiesel (*Tomić, M. D., Savin, L. Đ., Micić, R. D. et al., 2013*). CO emission is reduced by 30–50%, depending on the proportion of biodiesel in the mixture, mainly due to higher oxygen content and lower hydrogen and carbon content (*Ozsezen, A. N., Canakci, M., 2010*). *Ramesh, D., Sampthrajan, A. 2008*) found that the emission of CO_2 occurs in the process of burning biodiesel in the limits of 20% to 25% of the total combustion of fossil diesel, while Song, J. T., Zhang, C. H. (2008) give results according to which there is no significant difference in the emission of CO_2.

According to Gökalp, B., Soyhan, H. S., Sarac, H. I. et al. (2009) the addition of biodiesel fuel to standard diesel fuel improves the emission characteristics of diesel engines.

Although biodiesel has many advantages when it comes to fuel properties, it still has several properties that need to be improved, such as its lower calorific value, lower power output and its relatively higher emission of nitrogen oxides (*Gokalp, B., Buyukkaya, E., Soyhan, H. S., 2011*).

Diesel fuel can also be replaced with biodiesel produced from vegetable oils. Today, biodiesel is mainly produced from soybean and rapeseed oil. Soybean oil is of primary interest as a source of biodiesel in the United States of America, while many European countries deal with rapeseed oil, and countries with a tropical climate prefer to use coconut oil or palm oil (*Demirbas, A., 2007*).

After the soybean harvest, the grain is often processed to obtain high–value products, oil and soybean meal. Considering the significant use of soybean meal in animal feed and minor oil refining in Croatia, unused degummed oil can also be used as tractor fuel by mixing it with diesel. Soybean oil degumming is an economically inexpensive method that enables better use of soybean oil in terms of achieving better results of testing vegetable oils, with a simple processing technology (*Haldar S. K, Ghosh B. B., Nag A., 2009*).

It is known that vegetable oil has a positive influence on diesel fuel in terms of the effect of increasing the proportion of oxygen (oxide) in the fuel, which leads to better combustion and higher chemical energy of the fuel, as mentioned in the work of Altin R., Cetinkaya S., Yucesu H. S. et al. (2001) where better results were obtained using the addition of soybean oil to diesel fuel when testing power and torque. Schlick M. L., Hanna M. A., Schinstock J. L. (1988) states that the addition of soybean oil leads to better operation of the injection system precisely because of the increase in fuel viscosity, i.e. the injection pressure increases.

A mixture of soybean oil in concentrations above 60% causes significant changes in the operation of the engine and the formation of coke, but lower concentrations allow the use of soybean oil without modifications to the engine (*Engelman H. W., Guenther D. A., Silvis T. W., 1978; McCutchen, R., 1981*). McCutchen, R. (1981) state that the use of a mixture with indirect injection does not cause significant changes in the operation of the engine, while with the use of direct injection there are changes that are primarily visible in the failure of injectors and sticking of piston rings.

Wagner E. P., Lambert P. D., Moyle T. M. et al. (2013) state that the mixture of soybean oil and diesel causes a drop in power and torque and recommends the possibility of using gasoline in a mixture of diesel and soybean oil to reduce the increased viscosity caused by the addition of soybean oil. The results showed a solution to the viscosity problem, which contributed to solving the problem of power loss and torque both in laboratory research and in long–term operating conditions.

By increasing the concentration of soybean oil, a decrease in hourly and specific fuel consumption was determined compared to diesel fuel (*Pereira R. G., Tulcan O. E. P., Lameira V. J. et al. 2011*). Pereira R. G., Tulcan O. E. P., Lameira V. J. et al. (2011) also investigate the impact of exhaust emissions using soybean oil as a diesel fuel additive. The research results show an increase in the emission of CO, CO_2 and NO_x with the addition of soybean oil compared to the use of diesel fuel. The reason for the increase in emissions is the increase in fuel viscosity, which occurs as a result of the mixing of oil into the fuel, which results in a reduction in fuel dispersion after injection, and thus poorer combustion. In contrast to the aforementioned work, Altin R., Cetinkaya S., Yucesu H. S. et al. (2001) report an increase in CO emissions, but a decrease in CO_2 and NO_x emissions. In addition to the aforementioned influence of viscosity on fuel combustion, it is also necessary to pay attention to the fuel temperature during injection, as stated by Arapatsakos C., Moschou M., Sakalidou F. (2012), because a lower fuel temperature means a higher viscosity and vice versa, which leads to a reduction in combustion, i.e. to an improvement in combustion in case of higher fuel temperature. Also, it is stated that CO emission decreases with increasing fuel temperature, HC emission increases with increasing fuel temperature, and NOx emission shows an increase after the fuel temperature exceeds 30°C.

Based on the aforementioned, the aim of the paper is to determine the impact of mixing raw (degummed) soybean oil into mineral diesel fuel on the operating characteristics of a diesel engine with internal combustion in a tractor, and to determine the impact of using such a fuel mixture on the engine's rated power and exhaust gas emissions.

MATERIALS AND METHODS

The research is divided into two phases, the first is related to testing the technical characteristics of the engine, and the second to gas emissions and changes related to fuel consumption.

The research was carried out in the laboratory for engine characteristics testing at the Department of Agricultural Engineering, University of Zagreb Faculty of Agriculture.

Data on environmental factors (temperature, relative humidity and air pressure) were collected from the meteorological station of the Zagreb–Maksimir, Croatian Meteorological and Hydrological Service, which is located in the immediate vicinity of the laboratory. According to the data, the average temperature during the test was 23.5°C, with a relative humidity of 61% and an air pressure of 1019.2 hPa .

Four types of fuel, diesel fuel, and three mixtures of diesel fuel and soybean degummed oil in a concentration of 5% (S5), 10% (S10) and 20% (S20) were used for the purposes of the test. During the test, values such as braking force (kP), engine and PTO speed (min–1), hourly fuel consumption (l/h) and exhaust gas emissions were monitored.

The technical characteristics that are monitored are engine power and torque in relation to engine revolutions (rpm).

The Torpedo TD 7506 A tractor (Torpedo, Croatia) was used for the test, equipped with a four–cylinder air–cooled F4L 912 engine. According to the manufacturer, the rated power of the engine is 55 kW at 2400 rpm, while the torque is 243 Nm at 1600 rpm. The engine has direct fuel injection at a pressure of 175 bar.

The research of engine characteristics was carried out according to the OECD Code 2 regulations for the official testing of agricultural tractors. Two parts of measurements were carried out in 11 points (Figure 1).

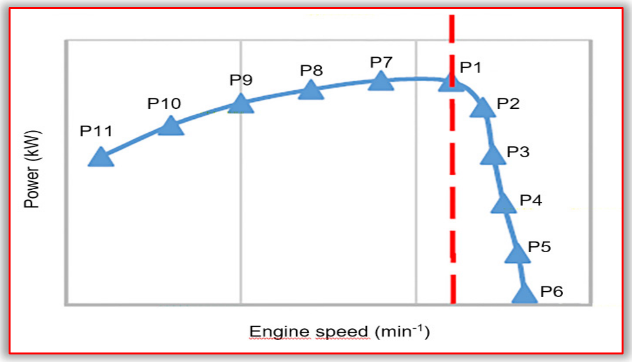

Figure 1 – Engine test points (source: Koronc Z., Filipović D., Fabijanić G., 2018)

The first part of the measurement is carried out in 6 points, where point P1 indicates the nominal power of the motor at the nominal number of motor revolutions. Point P2 represents the power achieved at 85% of the torque obtained at point P1. Point P3 shows the power achieved at 75% of the moment at point P2. Point P4 power at 50% of the moment realized at point P2, then point P5 at 25% of the moment, also at point P2. The last point of the first part of the measurement, point P6 represents the power achieved at the nominal speed without load.

The second part of the measurement was carried out in 5 points, in the range from nominal power to maximum torque, where for each subsequent point the number of revolutions was reduced by 200 engine revolutions per minute (P7 – characteristics at 2150 rpm, P8 – at 1950 rpm, P9 – at 1750 rpm, P10 – at 1550 rpm and P11 – at 1350 rpm).

For the purposes of testing, a hydraulic belt brake Schenck type U1–40 (Schenck RoTech GmbH, Germany) has been used. The hydraulic belt brake is connected to the tractor by means of a cardan shaft, that is, to the tractor's PTO shaft. The brake simulates different loads, i.e. braking forces, which can be used to monitor various parameters, such as tractor power, torque, fuel consumption and the concentration of exhaust gases depending on the applied braking force.

The number of revolutions of the PTO shaft was measured with the help of a digital measuring device Lutron DT 2236 (Lutron Electronics Co., Inc, US) with an accuracy of +/– 0.05 %.

The second part of the research refers to the examination of exhaust gases according to the ISO 8178–4:2017 standard for conducting a test on engine exhaust gases, more precisely to the concentration of CO, CO_2, HC and NO_x that are formed during combustion, and have the greatest impact on air pollution.

Testing is carried out through 8 points using the Maha MET 6.3 exhaust gas analysis device. (MAHA Maschinenbau Haldenwang GmbH & Co. KG, Germany) and probes for measuring exhaust gases, where point 1 represents the measurement of the concentration of gases at maximum engine power at the rated number of revolutions. Point 2 at 75% of the realized moment when measuring at point 1, point 3 at 50% of the realized moment at point 1, point 4 at 10% of the moment realized at point 1. Point 5 indicates the gas concentration at maximum moment, while point 6 indicates values of 75% of the achieved maximum torque, point 7 at 50% of the maximum torque. The last point, point 8, shows the values of the unloaded engine at the minimum number of revolutions.

The obtained values represent the average of the values through 3 measurements carried out in one hour, where statistical analysis using the SAS program was used.

Specific fuel consumption is also determined, which represents the amount of fuel consumed per unit of effective power. It can be expressed in kg/kWh or g/kWh. Hourly fuel consumption values at different loads were recorded using the Aquametro device Contoil DFM–BC (Aquametro Oil & Marine AG, Germany) which reads the achieved fuel flow on the DFM 8D flow meter.

Statistics analysis of data was brought with computer program SAS (SAS Institute 2002) using analysis of variance (ANOVA). The significance of differences between the observed parameters were indicated by F–test at the level of probability p = 0.05.

RESULTS

The research was carried out on engine characteristics: power, torque, hourly and specific fuel consumption at individual measurement points depending on the number of engine revolutions and load, and are shown in the following tables and graphs. Table 1 and Figure 2 show the achieved power of the diesel engine at individual measurement points when using different types of fuel and the achieved torque when using four types of fuel at individual measurement points.

Table 1. Maximum engine power and torque measured with different fuel types

	Diesel	S5	S10	S20
Max. Power (kW)	45.42 ±0.26 [ab*]	44.90 ±0.15 [c]	45.79 ±0.19 [a]	45.11 ±0.33 [bc]
Max. Torque (Nm)	202.92 ±0.29 [c]	211.29 ±0.84 [a]	211.26 ±0.66 [a]	207.73 ±0.57 [b]

*Means within the same row with different letters differ significantly ($p < 0.05$)

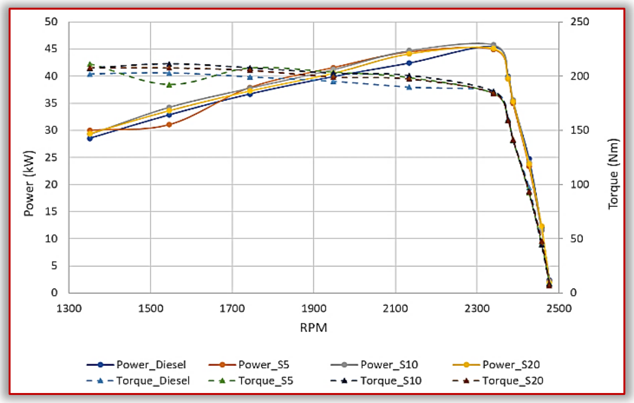

Figure 2 – Engine power and torque characteristics obtained with different fuel types

From point P1 to P6, there are no significant differences in power, somewhat larger differences can only be seen in the area of the curve from the point of the motor's nominal power to the maximum torque, that is, from point P7 to P11. The biggest difference in engine power was observed using S5 fuel at point P10 at 1600 rpm compared to the other three fuels. 9.42% less engine power was achieved when using S5 fuel compared to S10, or 7.81% compared to S20 and 5.56% compared to Diesel fuel. The average power of S10 fuel is higher by 0.99% that is 1.48% and 1.81% in relation to the average power of S20, S5 and diesel fuel.

The highest measured torque was achieved at points P10 and P11, but the biggest difference is visible at point P10 at 1600 rpm, where S5 fuel has the lowest torque compared to the other three fuels. That is, by using S5 fuel, torque was reduced by 5.3%, 7.51% and 9.07% compared to diesel, S20 and S10 fuel. Also, on graph 1, a decrease in torque is clearly visible, which can also be seen on the average value of the measurement. The highest average torque was achieved using S10 fuel, i.e. there is an increase of 0.65%, 1.15% and 2.04% compared to S20, S5 and diesel fuel.

Table 2. Hourly and specific fuel consumption measured with different fuel types

	Diesel	S5	S10	S20
Hourly consumption at max. power (L/h)	12.98 ±0.08 [a*]	11.99 ±0.04 [b]	13.00 ±0.06 [a]	13.01 ±0.09 [a]
Specific consumption at max. torque (g/kWh)	212.86 ±0.28 [b]	210.84 ±0.34 [c]	210.10 ±0.41 [c]	214.28 ±0.87 [a]

* Means within the same row with different letters diff significantly ($p < 0.05$)

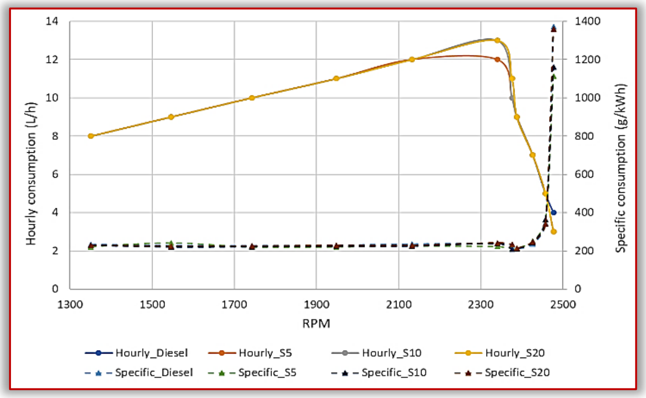

Figure 3 – Hourly and specific fuel consumption of the engine powered with different fuel types

Table 2 and figure 3 show the achieved hourly fuel consumption at individual measurement points when using different types of fuel and the specific fuel consumption when using different types of fuel.

As expected, the highest fuel consumption was achieved at the rated power of the engine, while at the point of rated power, a slightly lower consumption of S5 fuel was achieved, which also has the lowest achieved average fuel consumption. The reduction in consumption using S5 fuel was achieved by 1.02%, or 1.91% compared to S10 and S20 fuel, and the reduction compared to diesel fuel is 3%.

From the table 2 and figure 3, it is observed that there are almost no significant differences between the used fuels. On average, the lowest specific fuel consumption was achieved using S5 fuel, which is 7.46% lower than the highest average specific fuel consumption, i.e. diesel. On average, the highest specific fuel consumption is higher by 0.3%, or 6.74%, compared to S20 and S10 fuel. The lowest specific fuel consumption was achieved at point P2 at 85% of the torque achieved at point P1 using S5 fuel (nominal power point).

The results of the research of exhaust gas emissions are presented in tables, where the test was carried out through eight measurement points using different engine loads according to the standard for exhaust gas analysis ISO 8178–4:2007. The obtained results represent the average value obtained during three measurements carried out in one hour.

Table 3 shows the emission of carbon monoxide (CO) during the use of four different types of fuel at different measurement points.

Table 3. Emission of carbon monoxide at different measurement points

	Load (%)	CO (%) diesel	CO (%) S5	CO (%) S10	CO (%) S20
Rated engine speed	10	0.04	0.04	0.03	0.05
	50	0.03	0.03	0.04	0.04
	75	0.07	0.08	0.08	0.11
	100	0.34	0.44	0.43	0.39
Max. Torque	50	0.07	0.03	0.03	0.03
	75	0.22	0.17	0.16	0.18
	100	0.95	0.80	0.85	0.72

During the test at the nominal speed, an increase in CO emissions is visible with an increase in engine load. By using diesel fuel, the best result was achieved at maximum load at the rated speed compared to other fuels, i.e. by using S5, S10 and S20 fuel there is an increase in CO by 26%, i.e. 29%.

When measuring CO emissions at maximum torque, an increase was found in all three measurement points when using diesel fuel compared to other types of fuel. By using S20 fuel, the best result was achieved at maximum torque (100% load), where CO is reduced by 15.2% compared to S10 fuel. Also, a 24% reduction in emissions was observed when using S20 fuel compared to diesel.

Table 4 and show the measurement results for the emission of carbon dioxide (CO_2) at different measurement points.

Table 4. Emission of carbon dioxide at different measurement points

	Load (%)	CO_2 (%) diesel	CO_2 (%) S5	CO_2 (%) S10	CO_2 (%) S20
Rated engine speed	10	2.55	2.49	2.55	2.63
	50	5.45	5.08	5.14	5.14
	75	7.31	7.37	7.41	7.46
	100	12.23	10.54	11.43	9.50
Max. Torque	50	5,76	5.47	5.56	5.37
	75	8.79	8.65	8.65	8.61
	100	11.10	10.60	10.76	10.47

Again, no significant changes occur at the nominal speed up to 75% of the load. The changes are visible during the maximum load, where the best result is achieved by S20 fuel, i.e. a 22% reduction in CO_2 emissions was achieved compared to diesel fuel. The other two fuels also show a reduction in emissions during maximum load at rated rpm. Carbon dioxide emission at maximum torque shows the worst results using diesel fuel in all three measurement points compared to the other three fuels. That is, the use of soybean oil results in a reduction of CO_2 emissions at all measurement points. The biggest difference is visible in the maximum torque, where there is a reduction of 5.7% using S20 fuel compared to diesel fuel.

Table 5 shows the emission of NO x when using four different types of fuel and at different measurement points.

When measuring at a rated speed and a load of 50%, there is a 15% reduction in NOx emissions when using S5 and S10 fuel compared to diesel fuel, but with a further increase in load, there is a reduction in emissions in favor of diesel fuel, i.e. when using S20 fuel there is up to a 16% increase in emissions at maximum load at rated rpm compared to diesel fuel.

Table 5. Emission of nitrogen oxides at different measurement points

	Load (%)	NO_x (ppm) diesel	NO_x (ppm) S5	NO_x (ppm) S10	NO_x (ppm) S20
Rated engine speed	10	341.67	329.00	312.00	323.00
	50	997,00	873.33	846.67	957.67
	75	1436.33	1443.67	1402.67	1531.33
	100	1399.67	1473.33	1631.33	1623.33
Max. Torque	50	1092.67	979.67	1015.33	982.67
	75	1588.67	1428.67	1421.67	1562.67
	100	1601.00	1747.00	1838.00	2000.33

When measuring the maximum torque, there is an increase in NOx emissions at 100% load using soybean oil. By increasing the concentration and load there is an increase in NOx, the only decrease is visible at a load of 50% of the maximum torque where the values decreased by almost 10.34% if we look at the ratio of S5 and diesel fuel. An increase in emissions of 24.94% was achieved at maximum torque using S20 fuel compared to diesel fuel.

Table 6 shows the values measured during testing of four different fuels at different measurement points.

By measuring at the nominal speed, clear differences are visible in all measurement points. Increasing the load shows an increase in HC emissions for all types of fuel, and then at maximum load there is a sharp reduction in emissions, with the best result achieved using S20 fuel. The highest values of hydrocarbon emissions were measured using S5 fuel at 75% load at rated rpm.

Table 6. Emission of hydrocarbons at different measurement points

	Load (%)	HC (ppm) diesel	HC (ppm) S5	HC (ppm) S10	HC (ppm) S20
Rated engine speed	10	28.67	29.00	19.67	17.67
	50	29.33	39.00	20.67	28.33
	75	41.00	44.33	38.67	37.00
	100	12.23	15.67	23.00	9.67
Max. Torque	50	15.79	16.00	20.67	19.67
	75	22.30	29.67	29.67	23.67
	100	11.81	9.67	9.67	12.00

When measuring the maximum torque, there is an increase in hydrocarbon emissions at two measurement points using soybean oil as a fuel additive compared to diesel fuel. The biggest differences are visible during 50% and 75% of the maximum torque, with an increase of 30% (50% torque) and 22.1% at 75% torque when we look at diesel and S10 fuel. There are no significant differences in maximum torque, moreover the best result was achieved using S10 fuel.

CONCLUSION

The obtained results show the possibility of using soybean oil as an additive to diesel fuel, since the results of the engine's technical characteristics showed that there is no significant difference between diesel fuel and fuel with 5, 10 and 20% soybean oil. The influence of using soybean oil on engine power showed an increase in engine power. On average, the best result was achieved using S10 fuel. Using 10% soybean oil also achieved the best average result when measuring the maximum torque compared to the worst result achieved using diesel fuel. Energy consumption, i.e. hourly and specific fuel consumption also favors the addition of soybean oil. However, when measuring the emission of harmful gases, there are significant differences between diesel fuel and fuel with the addition of soybean oil, which could be solved with the addition of certain additives that are already used today to reduce the emission of harmful exhaust gases.

References

[1] Altin, R., Cetinkaya, S., & Yucesu, H. S. (2001). The potential of using vegetables oil fuels as fuel for diesel engines. Karabuk Technical Education Faculty, Karaelmas University, Turkey, 533–537
[2] Altıparmak, D., Keskin, A., Koca, A., & Gürü, M. (2007). Alternative fuel properties of tall oil fatty acid methyl ester – diesel fuel blends. Bioresource technology, 98 (2), 241–246
[3] Arapatsakos, C., Moschou, M., & Sakalidou, F. (2012). The Soy Oil Behavior on Diesel Engine. Department of Production and Management Engineering, Democritus University of Thrace, Greece, 175–181.
[4] Barnwal, B. K., & Sharma, M. P. (2005). Prospects of biodiesel production from vegetables oils in India. Renewable and sustainable energy reviews, 9 (4), 363–378
[5] Canakci, M., & Van Gerpen, J. (1998). The performance and emissions of a diesel engine fueled with biodiesel from yellow grease and soybean oil. In 2001 ASAE Annual Meeting (p. 1). American Society of Agricultural and Biological Engineers.
[6] Demirbas, A. (2007). Importance of biodiesel as transportation fuel. Energy policy, 35 (9), 4661–4670
[7] Engelman, H. W., Guenther, D. A., & Silvis, T. W. (1978). Vegetables oil as a diesel fuel. Diesel & Gas Engine Power Division of ASME Paper Number 78–DGP–19., New York
[8] Fang, T., Lin, Y. C., Foong, T. M., & Lee, C. F. (2009). Biodiesel combustion in an optical HSDI diesel engine under low load premixed combustion conditions. Fuel, 88 (11), 2154–2162
[9] Gokalp, B., Buyukkaya, E., & Soyhan, H. S. (2011). Performance and emissions of a diesel tractor engine fueled with marine diesel and soybean methyl ester. Biomass and bioenergy, 35(8), 3575–3583
[10] Gökalp, B., Soyhan, H. S., Sarac, H. I., Bostan, D., & Şengün, Y. (2009). Biodiesel addition to standard diesel fuels and marine fuels used in a diesel engine: effects on emissions characteristics and first–and second–law efficiencies. Energy & Fuels, 23 (4), 1849–1857
[11] Haldar, S. K., Ghosh, B. B., & Nag, A. (2009). Studies of the comparison of performance and emission characteristics of diesel engine using three degummed non–edible vegetables oils. Department of Chemistry, Department of Mechanical Engineering, Kharagpur India, 1013–1018.
[12] Hazar, H. (2009). Effects of biodiesel on a low heat loss diesel engine. Renewable Energy, 34 (6), 1533–1537
[13] Koronc, Z., Filipović, D., & Fabijanić, G. (2018). Karakteristike traktorskog dizel motora s direktnim ubrizgavanjem pri korištenju različitih vrsta dizelskog goriva. 46 Symposium „Actual Tasks on Agricultural Engineering“ Opatija, 117–126.
[14] Lapuerta, M., Armas, O., & Rodriguez–Fernandez, J. (2008). Effect of biodiesel fuels on diesel engine emissions. Progress in energy and combustion science, 34 (2), 198–223
[15] McCutchen, R. (1981). Vegetables oil as a diesel fuel–soybean oil. Beyond the Energy Crisis — Oppotunity and Challenge Volume III. Third International Conference on Energy Use Management, Berlin.
[16] Mustapić, Z., Krička, T., & Stanić, Z. (2006). Biodiesel as alternative engine fuel. Journal of Energy: Energy, 55 (6), 634–657. https://hrcak.srce.hr/7868
[17] Ozsezen, A. N., & Canakci, M. (2010). The emission analysis of an IDI diesel engine fueled with methyl ester of waste frying palm tree oil and its blends. Biomass and bioenergy, 34 (12), 1870–1878
[18] Pereira, R. G, Tulcan OEP, Lameira VJ, Filho DMES, & Andrade ET (2011). Use of Soybean Oil in Energy Generation. Fkuimenense Federal University, Bogota, 303–318.
[19] Qi, D. H., Geng, L. M., Chen, H., Bian, Y. Z., Liu, J., & Ren, X. C. (2009). Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil. Renewable energy, 34 (12), 2706–2713
[20] Ramesh, D., & Sampathrajan, A. (2008). Investigations on performance and emission characteristics of diesel engine with jatropha biodiesel and its blends. Agricultural Engineering International: CIGR Journal.
[21] Sahoo, P. K., Das, L. M., Babu, M. K. G., Arora, P., Singh, V. P., Kumar, N. R., & Varyani, T. S. (2009). Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. Fuel, 88(9), 1698–1707
[22] SAS Institute (2002). SAS/STAT User's guide. Ver. 9.1, SAS Inst., Cary, NC, USA.
[23] Schlick, M. L., Hanna, M. A., & Schinstock, J. L. (1988). Soybean and Sunflower Oil Performance in Diesel Engine. American Society of Agricultural Engineers, 1346–1348
[24] Song, J. T., & Zhang, C. H. (2008). An experimental study on the performance and exhaust emissions of a diesel engine fueled with soybean oil methyl ester. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 222 (12), 2487–2496.
[25] Taymaz, I., & Sengil, M. (2010). Performance and emission characteristics of a diesel engine using esters of palm tree olein / soybean oil blends. International Journal of Vehicle Design, 54 (2), 177–189
[26] Tomić, M. D., Savin, L. Đ., Micić, R. D., Simikić, M. Đ., & Furman, T. F. (2013). Effects of fossil diesel and biodiesel blends on the performances and emissions of agricultural tractor engines. Thermal Science, 17(1), 263–278
[27] Wagner, E. P., Lambert, P. D., Moyle, T. M., Koehle, M. A. (2013). Diesel vehicle performance on unaltered waste soybean oil blended with petroleum fuels. University of Pittsburgh, Department of Chemistry, Pittsburgh, 760–764.

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