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Long-term Wear and Performance Testing in Small Diesel Engines Using Waste Plastic Diesel

Khongdet Phasinam
Faculty of Food and Agricultural Technology, Pibulsongkram Rajabhat University, Phitsanulok 65000, THAILAND,

Thanwamas Kassanuk
Faculty of Food and Agricultural Technology, Pibulsongkram Rajabhat University, Phitsanulok 65000, THAILAND,

Abstract

Producing fuels from plastic waste can help to reduce pollution and energy issues by ensuring that the fuels can actually be used as alternatives. The objective of this research study is to compare the effects of using the diesel fuel from the plastic wastes on the single-cylinder engines by comparing the performance and wear of the engines with commercial diesel fuel and waste plastic diesel. There were two tests: 1) the engine performance test and 2) the engine wear test. According to the results of the engine performance test, it was found that the waste plastic diesel resulted in lower brake torque and brake power than those of the commercial diesel by about 3% at 2,200 rpm. However, the waste plastic diesel had a lower specific fuel consumption than that of the commercial diesel. As a result, the waste plastic diesel had a specific fuel consumption that was lower than that of commercial diesel by about 2%. Regarding engine wear, it was found that the waste plastic diesel caused slightly more wear than the commercial diesel. It was determined that waste plastic diesel was an alternative energy source with the potential of commercial diesel that did not require engine modifications.

Index Terms - Waste plastic diesel, Diesel engine, Engine performance, Engine wear.

INTRODUCTION

Thailand relies mainly on energy imports from foreign countries. It was discovered that imports initially met 60% of commercial energy demand. According to the data in 2019, it was found that the percentage of imported crude oil was high (87 percent) by comparing it to that of local crude oil. It also tended to rise because the volume of petroleum production could not meet the demand [1].

The serious development of renewable and alternative energies would reduce our dependence on importing and exporting fuels. Therefore, the government had policies promoting renewable and alternative energy produced in the country. The energy sources include wind power, solar energy, water power, biomass, wastes, biogases, and bio fuels. The targets were to increase the percentages of renewable and alternative energies in the form of electricity, heat, and biofuels in final energy use to 30% by 2037 [2]. Hence, driving the use of renewable and alternative energies is very important.

Moreover, the rapid economic expansion changed the consumption behaviors of people in the country. Consequently, problems with waste have occurred in the country. In 2018, there were 27.93 tons of waste, or 76,529 tons per day [3]. Most methods for disposing of the waste were not correct according to academic principles. This led to problems affecting the environment and the health of people [4]. However, these solid wastes have the potential to be used as energy [5]. Thus, adding value to the waste in order to produce renewable energies such as electricity, heat, or fuel was an alternative that did not only solve the environmental problems, but would also overcome the country's energy crisis [6].

Plastic wastes contain hydrocarbon compounds similar to fuels. As a result, plastic waste can be converted back into fuel by reducing the size of molecules to produce liquid fuel. This must be done through pyrolysis or thermal treatment [7] that decomposes substances with high molecular masses with heat in oxygen-free conditions. Temperatures range between 450 and 600 degrees Celsius [8]. These lead to three types of products: solids, liquids, and gases [9]. The liquids obtained by pyrolysis have properties similar to those of diesel fuel [10], [11].

According to previous studies, the properties of the oil produced from plastic waste were tested with the engine. It was found that the waste plastic diesel had a higher heating value, cetane number, specific gravity, viscosity, and flash point than the diesel fuel. By testing the oil with the engine, the brake power during the highest loads and specific fuel consumption were higher than 5–8%. The releases of nitrogen oxide and carbon dioxide were similar. The properties of the waste plastic diesel were similar to those of diesel fuel [12]–[15]. Nonetheless, although this oil could be a commercially renewable fuel, its quality is dependent on various factors, such as technologies, production systems, and raw materials. Thus, it was necessary to have supporting data about performance and engine wear in order to efficiently use the waste plastic diesel and to perfectly replace the commercial diesel fuel without affecting engines. The purpose of this research study is to compare the effects of using the diesel fuel from the plastic wastes on the single-cylinder engines by comparing the performance and wear of the engines with commercial diesel fuel and waste plastic diesel (WPD).

EXPERIMENTAL APPARATUS AND MATERIALS

I. Waste Plastic Diesel and Commercial Diesel

The tested diesel fuel was commercial according to the standards of the Department of Energy Business [16]. By comparing it to the diesel fuel produced from 100% plastic waste through pyrolysis at the waste plastic diesel refinery of Suranaree University of Technology, Thailand, the properties of most oil were consistent with the announcements of the department. All except the refinery values (Table I). The oil was classified as high speed diesel (HSD).

TABLE I WASTE PLASTIC DIESEL AND COMMERCIAL DIESEL PROPERTIES

Fuel Properties	Test Method	WPD	Commercial Diesel		
			Limit	HSD	LSD
Density at 15ºC (kg/m^3)	ASTM D 1298	0.8111	Min Max	0.81 0.87	- 0.92
Kinematic Viscosity at 40 ºC (cSt)	ASTM D 445	3.103	Min Max	1.8 4.1	- 8
Cetane Number	ASTM D 613	60	Min	50	45
Cetane Index	ASTM D 976	67	Min	50	45
Flash Point (ºC)	ASTM D 93	50.5	Min	52	52
Cloud Point (ºC)	ASTM D 97	15	Min	10	16
Oxidation Stability (g/m^3)	ASTM D 2274	17.8	Max	25	-
Sulfur Content (% w/w)	ASTM D 2622	0	Max	0.005	1.5
Ash Content (% w/w)	ASTM D 482	0.005	Max	0.01	0.02
90% (V/V) Distillation (ºC)	ASTM D 86	371.9	Max	357	-
Polyaromatic Hydrocarbons (% w/w)	ASTM D 2425	3.1	Max	11	-
Water Content (% w/w)	ASTM D 2709	0	Max	0.05	0.3
Lubricity Corrected (µm)	CEC F-06-96	350	Max	460	-

II. Engine Test

Experiments were conducted using a single-cylinder direct injection diesel engine with a naturally aspirated and water-cooled system. The test diesel engine was a new single-cylinder engine from HONMAR. Its model was the DH850E. It was ready to use. The diesel engine performance and wear test kit were from ESSOM. Its model was the MT502HD (Figure 1). The technical data of the diesel engine is shown in Table II. The schematic diagram of the experimental installation is shown in Figure 2.

TABLE II TEST ENGINE SPECIFICATIONS

Specifications	Honmar Model DH850E
Horse Power (hp)	6.7 at 3,600 rpm
Engine Type	Single-cylinder, 4-stroke
Cooling System	Air Cooled Type
Combustion System	Direct Injection
Cylinder Bore x Stroke (mm x mm)	78x62
Cylinder Volume (cm^3)	296
Engine Start System	Recoil
Fuel Capacity (liter)	3.5
Fuel Type	Diesel
Engine Oil Capacity (liter)	1.1
Engine Dimension (mm)	427x383x450

FIGURE 1 EXPERIMENTAL SETUP FOR ENGINE TESTING

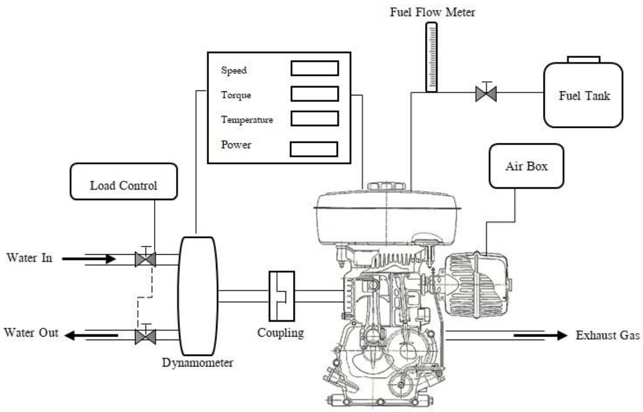

FIGURE 2 SCHEMATIC DIAGRAM OF THE EXPERIMENTAL INSTALLATION

III. Standards and Test

The test was divided into two parts. The first part was the engine performance test according to the ISO 1550:2016 Internal Combustion Engine–Determination and Method for the Measurement of Engine Power–General Requirements, which was used as the reference for specifying the load of the engine during the engine durability test. The performance consisted of 1) engine brake power, 2) engine brake torque, and 3) specific fuel consumption. The test started by warming the engine at 1,000 revolutions per minute (rpm) until the operating engine temperature was stable at 70 ºC, and the initial speed of the engine was set to 2,700 rpm. Then, the engine load was increased with the dynamometer until the speed of the engine was decreased. The value was recorded every 100 rpm until the speed of the engine was reduced to 1,700 rpm. Then, the test was over. The data was presented and analyzed in the form of an engine performance graph according to international standards. The second part of the test was the engine durability test, referring to the 200-hr Screening Test for Alternative Fuels or EMA 200-hr Test [18], which was the durability test standard for engines using alternative or renewable energies. In the test, the load was specified as the duty cycle as shown in Table III. The test was repeated for 18 hours (six cycles) and stopped for six hours in order to ensure that the temperature of the engine was equal to the ambient temperature. The test was repeated until it was tested for 200 hours. The durability of the engine was evaluated by measuring the properties of the engine oil every 50 hours. The examined properties included viscosity, density, alkalinity, and contaminated water quantity in order to study the effects of the waste plastic oil on the lubrication system of the engine and to measure the wear of other components of the engine. The metal and non-metal contaminants such as iron (Fe), aluminum (Al), copper (Cu) and chromium (Cr) were identified in order to find the wear of the other components after using the waste plastic oil because the different components were made of different materials. Therefore, the contaminants found in the engine oil could be used as guidelines for identifying the wear of the components.

RESULTS

I. Performance Test

Figure 3 shows the engine brake torque. It was found that the torque of the WPD was slightly lower than that of the commercial diesel. Especially at the speeds of 2,000–2,600 rpm, which were the normal speeds of the engine, the highest torque of the engine was at 2,200 rpm. The WPD had the highest torque of 11.0 Nm, while that of the commercial diesel was 12.2 Nm. That is, the torque of the WPD was lower than that of the commercial diesel by about 3%.

By calculating the engine brake power, it was found that the brake power tended to increase with speed. Additionally, both types of diesel fuel had similar results (Figure 4). The highest braking power of the engine was at a speed of 2,500 rpm. The commercial diesel had the highest brake power of 2.93 kW, while the commercial diesel had the highest brake power of 2.83 kW. However, the power from the WPD was averagely lower than that of the commercial diesel by 7% at speeds of 1,700–2,300 rpm.

Regarding the specific fuel consumption (SFC), it was found that the engine using the WPD had the lowest average SFC of 0.44 g/kW-hr. Similarly, commercial diesel had an average SFC of 0.41 g/kW-hr. The average SFCs were calculated at speeds of 2,000–2,600 rpm as shown in Figure 5.

TABLE III THE CYCLE OF THE EMA 200-HOUR DURABILITY TEST

Cycle Step	**Engine Speed (rpm)**	**Torque**	**Power**	**Time (min)**
1	RATED	–	RATED	60
2	85%	MAXIMUM	95%	60
3	90%	28%	25%	30
4	IDLE	0	0	30

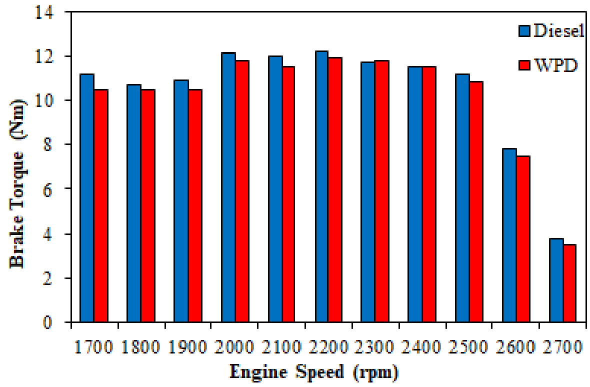

FIGURE 3 VARIATION OF BRAKE TORQUE VERSUS ENGINE SPEED

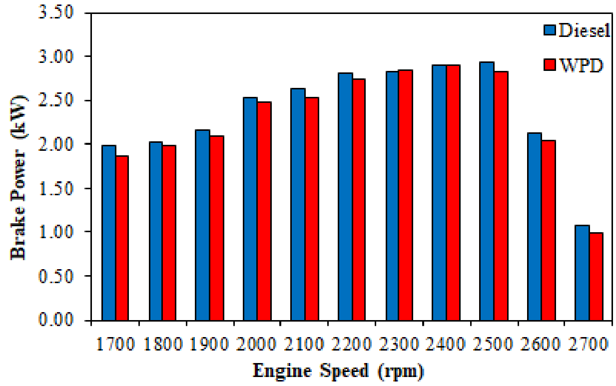

FIGURE 4 VARIATION OF BRAKE POWER VERSUS ENGINE SPEED

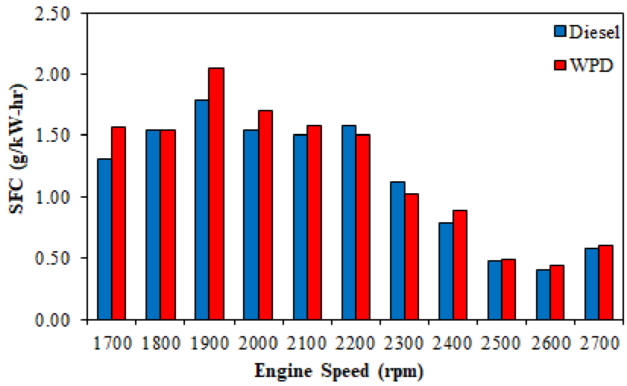

FIGURE 5 VARIATION OF SPECIFIC FUEL CONSUMPTION VERSUS ENGINE SPEED

II. Durability Test

The properties of the engine oil during the durability test of the commercial diesel and the WPD were shown in Table IV and Table V, respectively. The properties of the engine oil changed according to the time. The viscosity and density tended to increase, while the alkalinity decreased. By analyzing the metal and non-metal contaminants, it was found that the amounts of Fe, Pb, Cr, Cu, Al, and Si increased during the test.

TABLE IV THE PROPERTIES OF THE ENGINE OIL DURING THE COMMERCIAL DIESEL DURABILITY TEST

Properties	**Operating Hours (hr)**			
	50	**100**	**150**	**200**
Viscosity at 100 ºC (cSt)	15.20	16.40	17.10	17.80
Density at 100 ºC (kg/m^3)	852.10	853.00	854.30	855.90
Alkalinity (gKOH/g)	10.60	10.20	10.40	9.80
Fe (ppm)	22.30	23.10	25.33	25.76
Pb (ppm)	1.44	2.62	9.12	15.64
Cr (ppm)	0.90	1.60	2.60	3.90
Cu (ppm)	0.93	1.74	3.45	4.20
Al (ppm)	4.25	5.60	8.45	14.90
Si (ppm)	4.64	4.85	6.38	7.53

TABLE V THE PROPERTIES OF THE ENGINE OIL DURING THE WASTE PLASTIC DIESEL DURABILITY TEST

Properties	**Operating Hours (hr)**			
	50	**100**	**150**	**200**
Viscosity at 100 ºC (cSt)	15.10	15.80	16.40	17.50
Density at 100 ºC (kg/m^3)	852.54	853.00	853.40	854.20
Alkalinity (gKOH/g)	11.20	10.20	9.50	8.70
Fe (ppm)	23.25	24.00	26.30	26.95
Pb (ppm)	4.32	5.90	7.36	10.26
Cr (ppm)	0.85	1.60	2.65	3.55
Cu (ppm)	0.90	1.54	2.52	3.81
Al (ppm)	3.75	5.55	6.60	7.80
Si (ppm)	5.82	6.15	6.97	8.86

DISCUSSIONS

In this study, the performance and durability of the single-cylinder diesel engine using commercial diesel and waste plastic diesel were identified. By testing the performance of the engine at different speeds, it was found that the graphs of the brake torque, brake power, and specific fuel consumption changed in the same directions. The brake torque and brake power of the engine using waste plastic diesel were lower than those of the commercial diesel. Nevertheless, the specific fuel consumption of the waste plastic diesel and the commercial diesel were very similar. By testing the durability of the engine, it was found that the viscosity and density were increased. The alkalinity was decreased. The metal and non-metal contaminants were increased during the test. The engine consisted of many components, including static and dynamic components. Generally, the dynamic components were made of metals that had friction on the static components. The mentioned movements resulted in wear. Hence, the engine must have lubricant that does not only lubricate the components, but also cleans the metal components. Normally, lubricants have reactions with oxygen in the air. Then, it results in acidic substances and gum. These reactions occur at high temperatures that degrade the lubricants with increased acidity and viscosity. If the acidity of lubricants is increased, the metal components of machines will be eroded [19]. It is found that Fe has the highest amount since Fe is a main component of the parts of engines. Overall, the commercial diesel had a slightly lower amount of Fe than that of the other oils. Possibly, it was because the commercial diesel fuel had additives such as biodiesel in order to improve the lubrication. Thus, the test results could confirm that the waste plastic oil had the potential for being used in engines, and its qualities could be improved to be equivalent to those of commercial diesel.

CONCLUSION

This study examined the effects of the waste plastic diesel on the diesel engine. By comparing the performance and wear of the engine using waste plastic diesel and commercial diesel, it was found that the performance was slightly affected since the brake power was decreased by about 6%. The specific fuel consumption of waste plastic diesel and commercial diesel is very similar. Therefore, the brake thermal efficiency of the engine using waste plastic diesel was lower than that of the commercial diesel by only 1.6–3.0%. For the wear of the engine, it was found that the waste plastic diesel insignificantly resulted in more wear than the commercial diesel.

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REFERENCES

[1] Department of Mineral Fuels, "Energy for All," [Online], Available: https://dmf.go.th/public/list/data/index/menu/668, 2019.
[2] Department of Alternative Energy Development and Efficiency, "Alternative Energy Development Plan: AEDP 2018," [Online], Available: www.dede.go.th/ewt_dl_link.php?nid=54495, 2020.
[3] Pollution Control Department, "The Reports about the Community Waste Disposal Sites in Thailand in 2018," [Online], Available: http://infofile.pcd.go.th/Waste/Wst2018.pdf, 2018.
[4] Syamsiro, M., Saptoadi, H., Norsujianto, T., Noviasri, P., Cheng, S., Alimuddin, Z. and Yoshikawa, K., "Fuel Oil Production from Municipal Plastic Wastes in Sequential Pyrolysis and Catalytic Reforming Reactors," *Energy Procedia*, 47, 2014, 180–188.
[5] Kommana, S., Chowdary, P., G. and Madhuri, A.H.R., "Optimization of Injection Pressure and Compression Ratio of VCR CI Engine Fueled with Waste Plastic Oil Blended with Diesel," *International Journal of Mechanical and Production Engineering Research and Development*, 10, 3, 2020, 2585–2600.
[6] National Assembly Library of Thailand, "The Fuel from the Plastic Wastes," [Online], Available: https://library2.parliament.go.th/ejournal/content_af/2559/oct2559-1.pdf, 2016.
[7] Walendziewski, J., "Engine Fuel Derived from Waste Plastics by Thermal Treatment," *Fuel*, 81, 2002, 473-481.
[8] Beld, B.V., Holle, E. and Florijn, J., "The Use of Pyrolysis Oil and Pyrolysis Oil Derived Fuels in Diesel Engines for CHP Applications," *Applied Energy*, 102, 2013, 190–197.
[9] Senabut, J., Pinchaimoon, A. and Srithiang, K. "The Improvement in Quality of Fuel Oil by Pyrolysis of Polypropylene Using of an amorphous Silica Catalyst Made," *Industrial Technology Lampang Rajabhat University Journal*, 10,2, 2017, 12–23.
[10] Banar, M., Akyıldız, A., Özkan, A., Çokaygil, Z. and Onay, Ö., "Characterization of Pyrolytic Oil Obtained from Pyrolysis of TDF (Tire Derived Fuel)," *Energy Conversion and Management*, 62, 2012, 22–30.
[11] Ramanathan, A. and Santhoshkumar, A., "Feasibility Analysis of Pyrolysis Waste Engine Oil in CRDI Diesel Engine," *Energy Procedia*, 158, 2019, 755–760.
[12] Wattanavichien K. and Kannika, A., "Synthetic Diesel Fuel from Waste Plastic: Conversion and the Use in a Diesel Engine," in Pro. ME-NETT, 2019, 155–168.
[13] Gopidesi, R.K., Sankar, G.R., Kumar, A.D.P., Kumar, A.S. and Srimal, B., "Evaluating the Performance and Emission Characteristics of CI Engine with Waste Plastic Oil," *International Journal of Mechanical and Production Engineering Research and Development*, 9, 3, 2019, 1015–1020.
[14] Jatadhara, G.S., Chandrashekar, T.K. and Kumar, N.K., "Experimental Study on Characteristics of Direct Injection Compressed Ignition Engine using Waste Plastic Oil and Biodiesel Blends," *International Journal of Mechanical and Production Engineering Research and Development*, 10, 3, 2020, 2085–2094.
[15] Daniel, M.P., Kumar, K.V., Prasad, B.D. and Puli, R.K., "Performance and Emission Characteristics of Diesel Engine Operated on Plastic Pyrolysis Oil with Exhaust Gas Recirculation," *International Journal of Ambient Energy*, 38, 3, 2017, 295–299.
[16] Department of Energy Business, "Notification of the Department of Energy Business Re: Specification for Appearance and Quality of Diesel Oils," [Online], Available: http://elaw.doeb.go.th/document_doeb/TH/699TH_0001.pdf, 2020.
[17] International Organization for Standardization, "ISO 15550:2016 Internal Combustion Engines–Determination and Method for the Measurement of Engine Power–General Requirements," [Online], Available: www.iso.org/standard/70030.html, 2016.
[18] Department of Energy, "EMA 200 Hour Test Hydrogenated Soy Ethyl Ester and Diesel Fuel," University of Idaho, Department of Agricultural Engineering, USA. 1982.
[19] Kamthita P. and Limlertchareonwanit, T., "Acetic Acid Treatment of Used Lubricating Oil with Heavy Metals Adsorption by Activated Carbon from Water Hyacinth," *Thai Science and Technology Journal*, 27,1, 2018, 56–67.