

EXPERIMENTAL INVESTIGATION OF ETHANOL BLENDED WITH WASTE PLASTIC OIL AS AN ALTERNATIVE BIOFUEL IN A DIESEL ENGINE

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Abstract

The present study aimed to investigate and compare the effects of waste plastic oil/ethanol blends focusing on physical-chemical properties of the fuel and performance, combustion characteristics, and emissions of a diesel engine. Waste plastic oil produced by the pyrolysis process was mixed with ethanol. Experiments were conducted on WE10 (10% ethanol and 90% waste plastic oil, v/v) at four engine loads and a constant engine speed of 2,500 rpm. The experimental results showed that the blended fuel possessed higher cetane index, lower viscosity, density, flash point, and heating value when compared with diesel fuel. The engine test revealed that the use of WE10 led to an increase in indicated specific fuel consumption and a reduction in indicated thermal efficiency. The addition of ethanol to waste plastic oil led to increase in peak of heat release rate in consequence of the retarded start of combustion. The WE10 tended to increase NOX, CO, and HC with respect to diesel fuel. However, lower NOX was found for the combustion of WE10 when compared with WPO.

Keywords: Waste plastic oil, ethanol, diesel engine, performance, emissions

Introduction

Plastic waste has become an indelible component of municipal solid waste (MSW), as being used in a wide range of products due to its durability, light weight, and low cost. It is a mixture of various plastic products, mainly made from polyvinyl chloride (PVC), polystyrene

(PS), polyethylene-terephthalate (PET), low density polyethylene (LDPE), high density polyethylene (HDPE), and polypropylene (PP) plastics. Polyethylene (PE) and PS are the most available plastic types among municipal plastic waste (MPW). From the onset of invention of

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plastics, accumulation of plastic wastes gives rise to environmental problems. It may take billions of years for plastic to degrade naturally (Miandad *et al.*, 2016; Bridjesh *et al.*, 2018).

Plastic waste is managed by different techniques such as reducing, reusing, recycling, waste-to-energy (WTE), and disposal at landfill sites. Conventional mechanical recycling techniques such as sorting, grinding, washing, and extrusion can only recycle 15-20% of all plastic waste types. Beyond this level, the plastic becomes contaminated with materials like soil, dirt, aluminum foils, food wastes, and paper labels. The uncontrolled incineration and open burning of plastic waste have caused air and waterborne pollutants. Therefore, in recent years, various plastic-to-fuel (PTF) or WTE technologies such as gasification, pyrolysis, refuse derived fuel (RDF), and plasma arc gasification along with chemical recycling methods have gained significant attention for the management of MPW (Miandad *et al.*, 2017). Plastic waste is an ideal source of energy due to its high heating value and abundance. It can be converted into oil through the pyrolysis process and utilized in internal combustion engines to produce power and heat. Some researchers showed that the properties of the waste plastic oil (WPO) are practically like diesel fuel and the engine could be operated using neat WPO. Experimental engine results from previous studies have been reported that WPO exhibited higher brake thermal efficiency (BTE) and higher regulated exhaust emissions such as nitrogen oxides (NO_x), hydrocarbon (HC), and carbon monoxide (CO) with respect to diesel fuel combustion (Kalargaris *et al.*, 2017; Maithomklang *et al.*, 2017).

It is known that biofuel tends to improve combustion efficiency and emissions. Among oxygenated fuels, bioalcohol and biodiesel are widely used as alternative fuels in spark ignition engines and compression ignition engines, respectively. To extend the use of alcohol in compression ignition engines, alcohol is used as blend component in diesel fuel. Many studies have shown that combustion of biofuels is likely to reduce concentration of

toxic compounds in engine exhaust, particularly nitrogen oxide, and carbon dioxide that leads to the greenhouse effect. However, the use of blends containing very high percentages of alcohol in diesel engines can be limited by some poor properties of alcohol such as lubricity, viscosity, cetane number, and blending stability (Jamrozik, 2017; Sukjit *et al.*, 2017).

In this study, the effect of waste plastic oil blended with ethanol on physical-chemical properties of the fuel and performance, combustion characteristics, and emissions of a diesel engine characteristics were studied. The physical and chemical properties of test fuels were measured according to ASTM standards and engine experiments were conducted on a four-cylinder and naturally aspirated diesel engine to evaluate the performance, combustion characteristics, and emissions.

Materials and Methods

Test Fuels

To study the effects of the alternative biofuel on engine performance, combustion characteristics, and emissions. Ethanol was blended with waste plastic oil. It was previously reported that the presence of 10% ethanol in diesel fuel showed the emission benefits to improve NO_x and soot trade-off without any engine modification (Sukjit *et al.*, 2017). So, 10% ethanol was selected to blend with waste plastic oil (WE10) and its fuel properties, engine performance, combustion characteristics, and emissions were investigated. The basic physical and chemical properties of tested fuels and commercial diesel fuel as reference fuels were measured according to ASTM standards and was shown in Table 1.

Experimental Setup

The experiments were conducted on four-cylinder, four-stroke, naturally aspirated, water cooled, and direct injection (DI) diesel engine. The specifications of the engine are shown in Table 2. The schematic diagram of the experimental set up is presented in Figure 1. The tests were performed at a rated speed of 2,500 rpm and 4 different engine loads (50, 70,

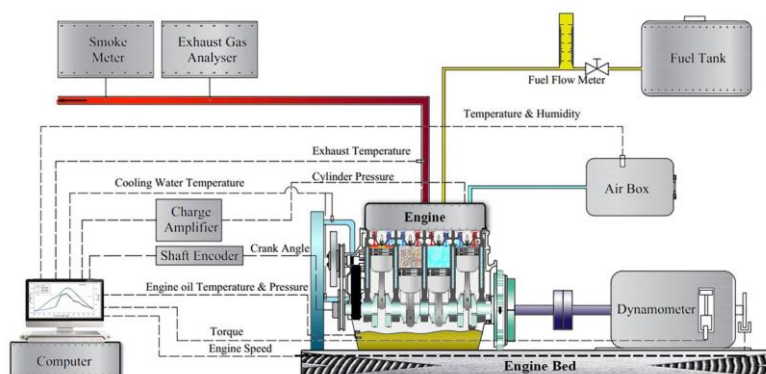


Figure 1. Schematic diagram of the experimental installation

Table 1. Physical-chemical properties of test fuels

Properties	Method	Diesel	WPO	Ethanol	WE10
Kinematic viscosity at 40°C (cSt)	ASTM D445	4.63	3.07	1.26	2.54
Specific gravity at 15.6°C	ASTM D1298	0.830	0.800	0.789	0.795
Density at 15.6°C (kg/m ³)	ASTM D1298	829	799	789	794
Flash point (°C)	ASTM D93	76	36	13.5	26
Gross calorific value (MJ/kg)	ASTM D240	45.39	44.90	29.7	43.13
Cetane index	ASTM D613	60.18	68.98	8*	68.03
Latent heat of vaporization (kJ/kg)	-	260	-	840	-

* Cetane number

Table 2. Specifications of diesel engine

Engine	Specification
Engine model	4JA1
Engine type	water cooled, 4-cylinder, 4-cycle, direct injection
Bore	93 mm
Stroke	92 mm
Compression ratio	18.4
Displacement	2449 cc
Rated power	64.9 kW at 4,000 rpm
Max. torque	171.5 N-m at 2,000 rpm

90, and 110 N-m). To record cylinder pressure traces, a Kistler 6052C pressure transducer mounted at glow plug adapter and connected was via a Kistler 5064C charge amplifier to a data acquisition board. The crankshaft position was measured using a Kistler 2164C crank angle encoder set. Other standard engine test rig instrumentation was used to monitor temperatures (intake air and exhaust gas), pressure (lubricating oil), humidity (intake air),

and mass flow rate (intake air and fuel). A Testo 350 analyzer was employed to measure CO and NO_x and Horiba MEXA-584L was used to evaluate HC. The specifications of the gas analyzing device is shown in Table 3.

Results and Discussion

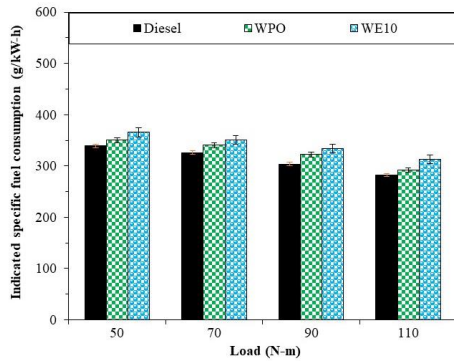
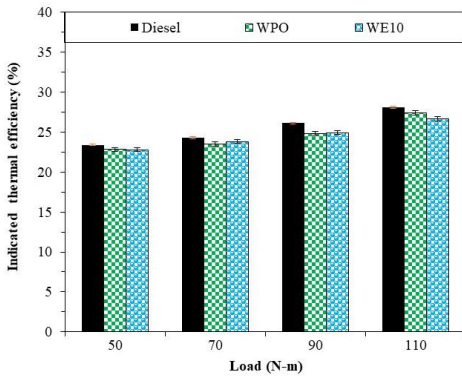
Engine Performance

In present section, performance parameters such as ISFC and ITE of the engine according to operation load for all the test fuels are presented and analyzed.

The variations of ISFC as a function of engine load for test fuels are shown in Figure 2. ISFC is a measure of how much fuel is consumed per power output. It can be seen that the ISFC decreased as the engine operating loads increased for all fuels. The waste plastic oil (WPO) showed higher ISFC when compared with diesel fuel, while the blended fuel (WE10) showed higher ISFC than the corresponding

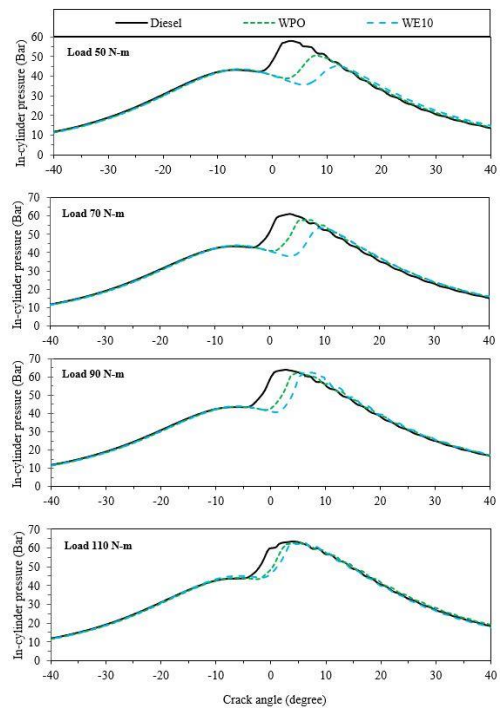
Table 3. Specifications of the gas analyzing device

Measured quantity	Measuring range	Resolution	Accuracy
TESTO 350			
NO	0 to 4,000 ppm	1 ppm	±5 ppm
NO ₂	0 to 500 ppm	0.1 ppm	±5 ppm
CO	0 to 10,000 ppm	1 ppm	±5 ppm
HORIBA MEXA-584L			
HC	0 to 20,000 ppmvol	1 ppmvol	-

**Figure 2. Indicated specific fuel consumption (ISFC)****Figure 3. Indicated thermal efficiency (ITE)**

waste plastic oil because of the lower calorific values of ethanol (Wei *et al.*, 2018).

The ITE which is inversely proportional to ISFC is shown in Figure 3. Higher ISFC was obtained from the combustion of waste plastic oil, resulted in the lower indicated thermal efficiency with respect to diesel fuel for all engine loads tested. With the addition of ethanol to waste plastic oil, it can be noticed that ITE

**Figure 4. In-cylinder pressure (ICP)**

obtained by WPO and WE10 was slightly different.

Combustion Characteristics

In-cylinder pressure (ICP) and rate of heat release (ROHR) for all engine operating loads are depicted in Figures 4 and 5, respectively. The first law of thermodynamics was used to calculate the heat release rate with Equations (1) (Sukjit *et al.*, 2018)

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma-1} p \frac{dV}{d\theta} + \frac{1}{\gamma-1} V \frac{dp}{d\theta} \quad (1)$$

where $dQ/d\theta$ is the rate of heat release, p is the in-cylinder pressure, V is the combustion chamber volume, and θ is the crank angle. The constant specific heat ratio (γ) of 1.35 was used for the calculation.

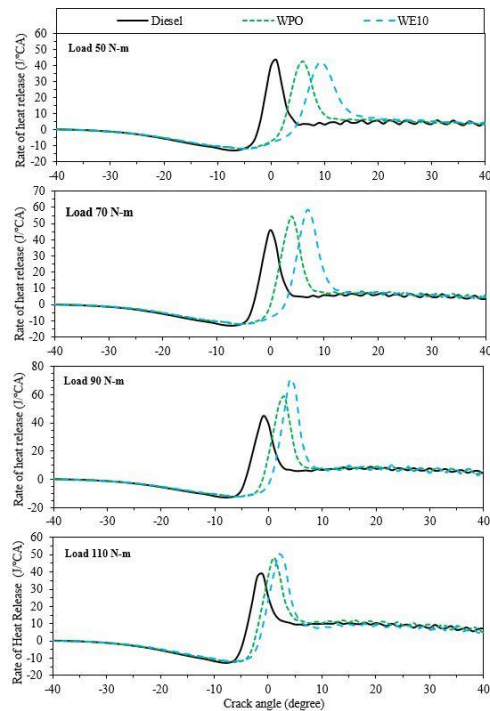


Figure 5. Rate of heat release (ROHR)

The start of combustion refers to the crank angle at which heat is released at the beginning of the premixed combustion phase. The results in Figure 5 reveal that the start of combustion decreased (shorter ignition delay) as the engine operating loads increased for WPO compared with diesel fuel. The addition of ethanol to waste plastic oil tended to delay the start of combustion, resulting in longer ignition delay. The lower cetane number of ethanol can be used to justify such increase in ignition delay (Choi and Jiang, 2015). In addition, the higher latent heat of vaporization of ethanol tended to increase mixing time between air and fuel, leading to the delay in the start of combustion. This longer ignition delay tended to reduce the temperature of in-cylinder

gas mixture. With longer ignition delay, there was higher volume of premixed mixture ready to combust when combustion started. Consequently, the higher peak of premixed combustion than in case of diesel fuel due to the longer ignition delay of the ethanol blend was observed (Sukjit *et al.*, 2017).

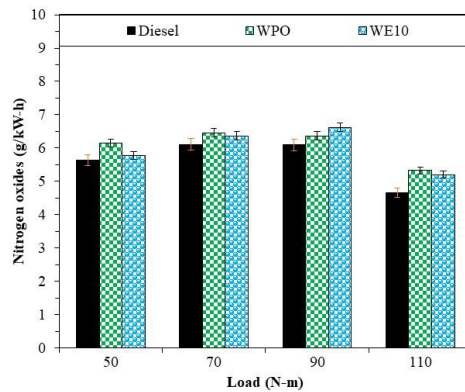


Figure 6. Nitrogen oxides emissions (NOX)

Emissions

In this section regulated emissions such as NO_x , CO, and HC by the combustion of test fuels were discussed.

NO_x emissions are shown in Figure 6. Oxides of nitrogen present in emissions is the combination of nitric oxide (NO) and nitrogen dioxide (NO_2). The formation of NO_x is highly dependent on high combustion temperature, long residence time, and high oxygen content. Comparing WPO with diesel fuel, there was an increase in NO_x emissions. However, the presence of ethanol in WPO was beneficial to reduce NO_x emissions because of the higher latent heat of evaporation of ethanol which needed more energy to vaporize before mixing with the air, resulting in the lower in-cylinder temperature during the combustion process (Yilmaz and Davis, 2016; Sukjit *et al.*, 2017; Jeevahan *et al.*, 2018). In addition, the lower heating value of ethanol can be another reason of the lower combustion temperature which lower NO_x emissions can be obtained.

CO and HC emissions are shown in Figures 7 and 8. The formation of CO emissions

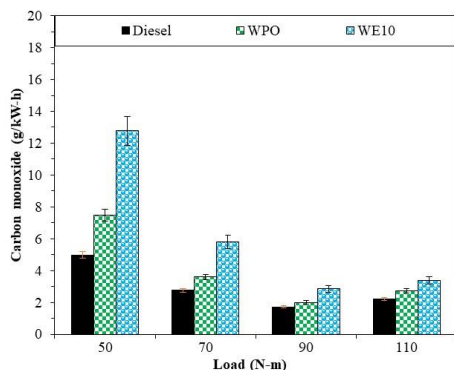


Figure 7. Carbon monoxides emissions (CO)

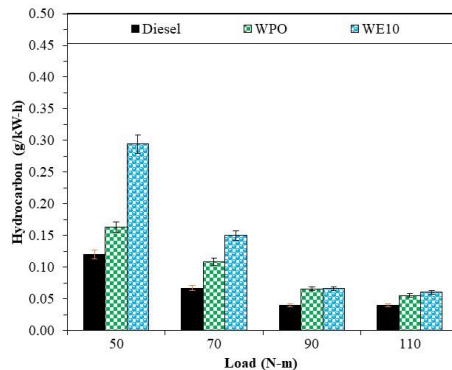


Figure 8. Hydrocarbon emissions (HC)

is due to the insufficient oxygen level during the combustion. This lesser oxygen molecule reacts with the carbon molecules within the low temperature combustion process. In a diesel engine, the formation of CO emission is the symptom of an incomplete combustion process. Also, the air- fuel rich zone and improper mixing of the charge are the other factors for the formation of CO emissions. The formation of hydrocarbons is mainly depending on the air fuel ratio, chemical properties of tested fuels, spray characteristics, and operating conditions (López *et al.*, 2015; Gowtham *et al.*, 2019). It can also be noticed that the CO and HC for WPO and WE10 were higher than for diesel fuel, which may be apart from the delay of combustion, the high latent heat of vaporization of ethanol which tended to promote incomplete combustion can be used to justify the increase in CO and HC (Sukjit *et al.*, 2012).

Conclusions

The effects of waste plastic oil/ethanol blends on basic physical-chemical properties of test fuels, performance, combustion characteristics, and emissions were studied. According to the experiment outcomes, the following conclusions were drawn:

i) The blended fuels (WE10) possessed higher cetane index, lower viscosity, density, flash point, and heating value when compared with diesel fuel.

ii) The use of WE10 led to an increase in indicated specific fuel consumption and a reduction in indicated thermal efficiency.

iii) The addition of ethanol to waste plastic oil lead to increase in peak of rate of heat release in consequence of the retarded start of combustion due to higher latent heat of vaporization and lower cetane number of ethanol.

The WE10 tended to increase NO_x, CO, and HC was obtained with respect to diesel fuel. However, lower NO_x was found for the combustion of WE10 when compared with WPO.

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