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Development of Environmentally Friendly Fuel Mixtures Based on Tamanu Oil and Pertasol, as Well as Performance Testing on Gasoline Engines

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ABSTRACT

Attention to greenhouse gases is carried out by reducing CO_2 emissions. Emission reduction is achieved using mixed fuels, primarily derived from plant oils. The pertasol-diethyl ether and tamanu oil (PDETO) fuel mixture were tested using a spark ignition engine. The research objective is to obtain fuel specifications and test engine performance using the resulting fuel. Mixed fuels were created from various compositions with codes ranging from BE0 to BE10. Performance testing was conducted using a 110-cc gasoline engine with specific specifications using mixed fuels and compared to commercial gasoline. The research results indicate that engine torque, power, and MeP are higher when using mixed fuels BE0 – BE10 than retail gasoline. The maximum torque that can be achieved is 8.51 NM at 5000 rpm using BE10 mixed fuel, higher than the maximum torque of commercial gasoline, which is 6.81 NM. The highest full power is generated by BE10 fuel, at 7.75 HP at an engine speed of 7000 rpm. The minimum capacity is produced by BE0 fuel, with a power of 6.78 HP at an engine speed of 7000 rpm. Optimal SFC occurs in the BE0 fuel mixture at 7000 rpm engine speed at 0.25 kg/Hp·h. BE10 thermal efficiency reached 31.8%, which is better than commercial gasoline.

Keywords: greenhouse, ignition, mixed fuel, power, torque.

INTRODUCTION

Biofuels derived from biomass residues and vegetable oils can be suitable and sustainable alternative fuels (Al-aseebee et al., 2023; Al-aseebee and Naje, 2023; Budianto et al., 2014; Khairil et al., 2018; Lappas, Bezergianni and Vasalos 2019; Mirzayanti et al., 2018; Ro et al., 2023; Shyurova et al., 2020; Sumari et al., 2019). Oxygenated biofuels from biomass, such as alcohols and ethers, have proven viable alternatives to fossil fuels. Blending oxygenated fuels with gasoline can enhance the octane rating and facilitate a more complete combustion process, thus improving engine thermal efficiency. These oxygenated fuels have the potential to significantly reduce engine exhaust emissions compared to gasoline due to their oxygen content (Awad et al., 2018; Awad et al., 2018; Bae & Kim, 2017).

In agricultural countries, a significant portion of fruit and vegetable yields (20–30%) is discarded due to inadequate storage and distribution facilities. As the population continues to grow, so does the demand for food. Consequently, a substantial number of unused fruits and vegetables are discarded daily. This condition presents a significant challenge for researchers to make the process more efficient, starting from agricultural processing, storage, processing, and distribution. Agricultural waste contributes to global warming in the food processing industry, which has driven the innovation of renewable energy due to the ongoing energy crisis. Several researchers researched evaluating the level of greenhouse gas emissions during the burning of several types of agricultural biomass. This study aims to evaluate greenhouse gas emissions during biomass burning and compare greenhouse gas emissions from several different types of biomass. This research also aims to evaluate the potential of biomass as a renewable energy source (Wasilewski et al., 2022). This research was carried out by burning several types of agricultural biomass, namely solid biomass in the form of pellets and liquid biomass in the form of biodiesel. During combustion, greenhouse gas emissions such as CO_2, CH_4, and NO_x were measured using a portable flue gas analysis system, Testo 350. In addition, analysis of variance (ANOVA) was also used to analyze the results obtained. The main conclusion of this research is that biomass can be used for energy purposes in a variety of ways, and the benefits vary greatly depending on the system used. Bioenergy systems can contribute to climate change mitigation, but the use of biomass resources requires careful consideration of how to target the actions taken concerning the available resources. The research results also show that greenhouse gas emissions from solid biomass in the form of pellets and liquid biomass in the form of biodiesel can vary depending on the type of biomass used and the combustion system used (Wasilewski et al., 2022).

Biofuel is present as an alternative to fossil fuels. It has the advantages of low carbon emissions and oxygenation properties. Some of the fuels produced are alcohol-based and are used in several countries. The general alcohol concentration of 10% has been the standard in its application by previous researchers. Developing blends with up to 20% ethanol is necessary to improve vehicle performance (Bae & Kim, 2017). This experiment was conducted using four variations of ethanol-gasoline Fuel and compression ratios. The testing demonstrated that high octane fuel mixtures and high compression ratios can optimize engine performance and reduce exhaust emissions compared to standard fuels. Performance improvements were observed in engine revolutions (1500–4000 rpm) (Balki MK, 2014a; Celik, 2008; Hasan et al., 2018). Ethanol-gasoline fuel blends have a significant impact on engine performance during cold-start conditions. Adding 30% v/v ethanol to the Fuel can increase octane rating and accelerate combustion. This condition indicates that adding ethanol to the Fuel can optimize engine cold-start conditions, improve engine performance, and reduce exhaust emissions compared to additive fuels. Adding ethanol to the Fuel contributes to achieving more complete combustion (Balki MK, 2014b).

Performance testing of a single-cylinder 4-stroke SI engine with a compression ratio of 7/1 using ethanol-methanol-gasoline mixtures (3–10 vol.%), ethanol-gasoline mixtures, and methanol-gasoline combinations showed that an increase in torque, power, and specific fuel consumption occurred with a ten vol.% ethanol-methanol-gasoline solution. This condition is due to the lower calorific value of the ethanol-methanol-gasoline mixture (10 vol.%), which can optimize combustion (Elfasakhany, 2015). Performance tests of a large-capacity S.I. engine with four cylinders using a standard 95 octane fuel mixed with 10% ethanol and iso-butanol (5% v/v, 10% v/v, and 15% v/v) demonstrated that the ethanol 10% v/v and iso-butanol 15% v/v fuel mixture can improve engine performance (torque, power, and thermal efficiency). However, specific fuel consumption values decreased compared to standard Fuel (Zaharin et al., 2018).

The effect of ternary fuel blends (3–10 vol%) such as ethanol-methanol-gasoline (EM) resulted in increased engine performance (torque, power, and volumetric efficiency) at engine speeds (2600–3400 rpm). The addition of ethanol-gasoline (10–30%) significantly optimized power output and specific fuel consumption in four-cylinder and single-cylinder S.I. engines (Doğan et al., 2017; Hsieh et al., 2002; Manikandan & Walle, 2013; Saikrishnan et al., 2017). The torque increase is attributed to adding methanol, ethanol, and butanol to the combustion chamber. On the other hand, thermal efficiency decreases due to the increased oxygen content introduced into the combustion chamber, affecting a slight delay in engine ignition. Specific fuel consumption in the butanol-gasoline mixture decreases compared to alcohol-gasoline blends with higher calorific values (Li et al., 2017).

Because ethanol has a lower calorific value than gasoline, it affects the fuel flow rate into the combustion chamber, necessitating an increase in the fuel fraction by adding ethanol. When added to the Fuel, a high ethanol fraction results in a lean mixture, enhancing combustion (Iodice et al., 2018). Adding iso-butanol as an additive to the ethanol-gasoline fuel mixture helps achieve complete combustion, increasing engine power and reducing fuel consumption. The maximum power output is 68.93 kW, occurring at an engine speed of 5000 rpm (B10-B15), with a minimum specific fuel consumption of 315.17 g/kWh at the same engine speed (B10-B15) (Zaharin et al., 2018).

This study presents a novel method for producing bioethanol from pomegranate waste fermented using Saccharomyces cerevisiae (yeast). Engine performance testing using various ethanol-fuel blends (10%, 15%, 20%, and 25%) at 1300-1800 rpm engine speeds revealed that adding ethanol improved engine performance. A 15% ethanol-fuel blend exhibited optimal thermal efficiency at full load compared to non-additive fuels. Meanwhile, specific fuel consumption for the 15% ethanol blend was lower than all other blends (Duarte et al., 2021).

Previous research used ethanol and methanol as raw materials. Methanol and ethanol are produced through long fermentation. This condition is not adequate. Some researchers have harnessed Tamanu oil (TO) as Fuel through transesterification or cracking (Budianto et al., 2018; Budianto et al., 2015; Budianto et al., 2014; Budianto et al., 2019; Hajj et al., 2019; Sumari et al., 2019). These processes were carried out to reduce the Fuel's viscosity, making it suitable for use as a motor vehicle fuel. However, the transesterification and cracking processes increased production costs. Researchers have explored the direct utilization of plant oil extracts to mitigate production costs, especially those with lower viscosity.

One interesting research is research conducted by Gorsky et al. (2022). This research is about the analysis of the physico-chemical properties of the diethyl ether/sunflower oil mixture, as well as changes in emissions in the AD3.152 diesel engine. This research also examined several properties of the tested mixtures in detail, such as density, kinematic viscosity, cold filter blockage point, lower heating value, flash point, and surface tension. This research uses several methods to test the physico-chemical properties of the diethyl ether/sunflower oil mixture, such as measuring density, viscosity, cold filter blockage point, lower heating value, flash point, and surface tension. The measurement methods used include ASTM D7042, ASTM D240-02:2007, ISO 304, ISL FPP 5Gs, Cleveland Open Cup, and EN ISO 12156-1:2006. All measurements were carried out three times and the average value of these repetitions was used as the final result. The research results show that the diethyl ether/sunflower oil mixture can reduce diesel engine exhaust emissions, and has a higher lower heating value compared to conventional diesel fuel. In addition, this research also shows that this mixture has adequate physicochemical properties to be used as an alternative fuel in diesel engines. This study concludes that the diethyl ether/sunflower oil mixture can be considered a promising alternative fuel for diesel engines. In addition, this mixture has a higher lower heating value compared to conventional diesel fuel. Therefore, this study suggests that diethyl ether/sunflower oil blends may be an attractive alternative to conventional diesel fuel (Górski et al., 2022).

Other researchers conducted research on the lubricating properties of selected plant and animal raw materials, such as rapeseed oil, rapeseed oil methyl esters, and esters with goose fat. This study discusses the relationship between the degree of unsaturation and lubricant properties and identifies oleic acid as the best lubricant among the tested compounds with oxygen groups(Gardyński & Kałdonek, 2020). The main discussion in this research is about the lubricating properties of selected plant and animal raw materials, such as rapeseed oil, rapeseed oil methyl ester, and ester with goose fat. This study discusses the relationship between the degree of unsaturation and lubricant properties and identifies oleic acid as the best lubricant among the tested compounds with oxygen groups. Apart from that, this research also discusses the effect of temperature and contact time on the lubricating properties of the tested compounds. The results of this research can make an important contribution to the development of more environmentally friendly and efficient lubricants (Gardyński et al., 2020).

Researchers observed that the viscosity of TO is not excessively high when used in conjunction with the base gasoline fuel, pertasol. The solubility of TO in pertasol and the resulting octane number are essential factors in creating a composition that meets standards. Research on biofuel production from a blend of pertasol, TO, and diethyl ether, which provides fuel specifications that meet standards and performance testing on engines, is an exciting endeavour.

MATERIALS AND METHODS

Materials and tools

The fuel mixing dosage is according to Table 1. The first step is to mix 950 ml of pertasol with 50 ml of diethyl ether (DE) using a closed measuring flask and shake it thoroughly so that it is thoroughly mixed. Composition mixture produces BE0. The second step of mixing BE2.5 comes from 925 ml of pertasol with 50 ml of DE and 25 ml of Tamanu oil (TO) added to a closed volumetric flask, shaken to mix thoroughly. The steps for the BE5, BE7.5, and BE10 mixtures were carried out in the same way as the second step with the capacities of PDTO according to Table 1. DE is a colorless liquid with high volatility and is flammable. DE has a very high cetane number, reasonable density, low auto-ignition temperature (AIT), high oxygen content, and solubility properties. Therefore, DE is very suitable for application in S.I. and CI engines (Issayev et al., 2020; Yadav et al., Dewangan, and Mallick 2018; Yesilyurt and Aydin 2020). Pertasol is a clear-coloured solvent (solvent) obtained from hydrocarbon naphta in the formation of paraffin, cycloparaffin or naphthenic, and aromatic components in atmospheric distillation units with paraffinic and asphaltic crude (Kuntari & Barkasih, 2018). TO has the characteristics of high viscosity and fatty acid content. The physical appearance of TO is dark green, thick, and has a robust and distinctive aroma. TO has a flash point of 146 °C, fire point of 160 °C, density of 0.905 kg/m^3, and kinematic viscosity of 4.21 cSt (Ayyasamy et al., 2018; Karthik et al. 2020; Parthasarathy et al. 2020). Figure 1 shows the physical appearance of a mixture of PDTO. BE0 is clear or colorless because the mixture contains pertasol and diethyl ether. The mix BE2.5, BE5, BE7.5 and B.E. 10 shows a physical appearance with a yellowish colour due to the mix of TO.

Table 1. Composition of 1000 ml PDTO Fuel Blend

Fuel Component	BE0	BE2.5	BE5	BE7.5	BE10
Pertasol CA	950	925	900	875	850
Diethyl ether	50	50	50	50	50
Tamanu oil	0	25	50	75	100

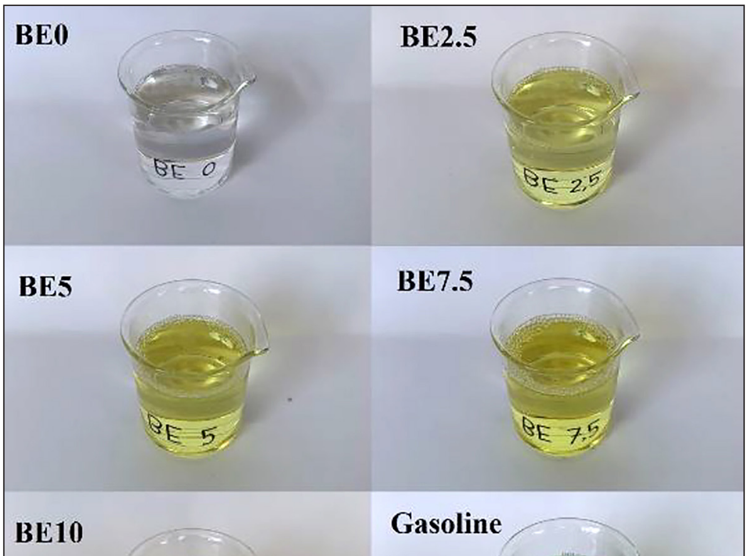

Figure 1. Appearance of BE0-BE10 fuel and commercial fuel as a comparison

Machine specifications in testing

The resulting mixed fuel is then tested for performance in a gasoline engine. The characteristics of the machine used are shown in Table 2. This engine is commonly used in motor vehicles with well-known brands worldwide. Test engine performance using a dyna test with several meters measured. The parameters measured are engine torque, power, effective pressure, fuel consumption, and thermal efficiency.

Test engine performance

The research was conducted in the combustion motor laboratory and experimentally designed to determine the effect of the PDTO on the performance of 1-cylinder SI engines. The method used is to mix PDETO with levels of 0%, 2.5%, 5%, 7.5%, and 10% on SI motors with variable speed (variable speed test) 4000, 5000, 6000, 7000, 8000, and 9000 rpm with a fully open throttle. The test was carried out by opening the throttle to complete, and then the rotation was adjusted by setting up a Super-Dyno 50L type dyno test chassis.

Regulation of engine speed is carried out through the loading of the dyno test chassis that has been coupled with wheels. Figure 2 shows the steps performed during machine testing. First, refuelling the fuel tank is then pumped to the pump module and pressure regulator. Both start the SI-Matic engine at idle speed (± 2000 rpm) for 10 minutes to achieve a steady state or stationery. The third opens the butterfly valve to open the throttle fully. In this condition, the engine speed is 9000 rpm, the maximum revolution of the SI engine. If the engine speed is stable, the four recording processes on the CPU monitor include power, torque, and fuel consumption time.

Table 2. Machine character in testing

Detail	Specifications
Machine	SOHC with air cooling, eSP
Fuel supply system	Injection (PGM-FI)
Bore × xtep	50 × 55.1 mm
Transmission type	Automatic, V-Matic
Compression ratio	9.5: 1
Maximum power	6.7 kW (9.1 PS / 7500 rpm)
Maximum torque	9.4 Nm (0.96 kgf·m) / 6000 rpm
Starter type	Pedals and electric
Clutch type	Automatic, centrifugal, dry type
Spark plug	Iridium

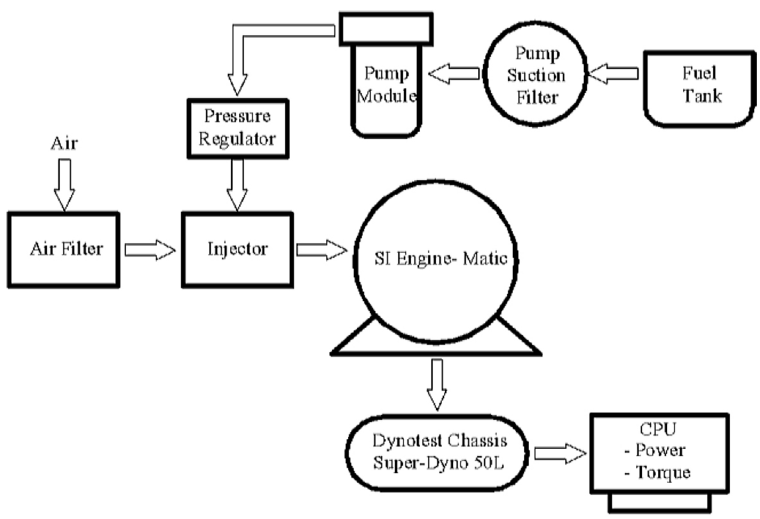

Figure 2. Engine performance testing scheme

RESULTS AND DISCUSSION

Table 3 PDTO fuel blend specifications and commercial fuel as a comparison. RON PDTO Blend fuel is located at 91–97 while commercial fuel is 90. The higher the Tamanu oil content, the higher the RON PDTO fuel mixture, this shows that Tamanu Oil increases the RON PDTO Blend fuel. The results of this research are different from the research of Gorsky et al which used DEE and sunflowers which produce biodiesel fuel. This research produces bio-gasoline fuel with a better octane number than commercial fuel. The RON PDTO fuel mixture yield is lower compared to Carlson et al.'s 2023 research on petroleum refining for low-carbon spark ignition biofuel. This research shows the mixing properties applied to BSI Co-Optima bio-blendstocks. Mixing bio-blend stocks has a significant effect on increasing the octane number (RON) of gasoline. This suggests that bio-blendstocks can improve gasoline quality by increasing the octane number, which is an important indicator of fuel performance. Therefore, blending bio-blend stocks can provide added value fo gasoline producers by improving the quality of the fuel produced (Carlson et al., 2023). Table 3 also shows that the density of the PDTO fuel mixture is in the range of 747–770 kg/m^3, this value is lower than the density of the diesel-type biofuel from a mixture of sunflower oil and DEE which is in the density range of 0.87-0.92. The LHV calorific value of the PDTO fuel mixture is in the range of 10,545–10,791 kcal/kg. Increased levels TO increase heating value. The LHV value of this research fuel is higher than that of grilled fuel made from sunflower oil and DEE, with the highest LHV value of 8922.97 kcal/kg (Górski et al., 2022). The PDTO fuel blend specification has advantages in RON and LHV values compared to mixed biofuel from sunflower seed oil and DEE.

Torque is a measure of the engine's ability to produce work. The torque from the motor helps increase the speed of the vehicle. Figure 3 shows that the highest maximum torque is produced on BE10 fuel, with a maximum torque of 8.51 Nm. at an engine speed of 5000 rpm. It happens because the higher the engine speed, the higher the flow turbulence entering the combustion chamber, which causes the mixing of air with Fuel to be better, and the propagation of the fire is also faster so that the torque will increase. After the spin gets up, the greater the losses that occur. Some losses that may arise in high revs include friction and the presence of incomplete combustion. The faster the engine speed, the greater the conflict.

In addition, the combustion of a mixture of Fuel and air in the combustion chamber also takes time. At high revs, When the rotation is high, the combustion time becomes short, and the combustion reaction becomes incomplete or, in

Table 3. Specifications for PDTO fuel blend and one of the commercial fuels in Indonesia

Parameter	Metode	Commercial fuel		PDTO Fuel Blend					Unit
		Min	Max	BE 0	BE 2.5	BE 5	BE 7,5	BE 10	
Research octane number	ASTM D-2699	92	92	91	93	94	96	97	%RON
Nilai Kalor				10,545	10,669	10,682	10,693	10,791	kcal/Kg
Density	ASTM D-4052	715	770	747	752	758	762	770	kg/m3
Distillation at 90 recovery	ASTM D-86								
IBP				52	51	53	53	57	°C
10% vol		-	74	78	80	80	78	80	°C
50% vol		77	125	97	97	98	99	101	°C
90% vol		130	180	123	127	130	134	140	°C
End point		-	215	159	158	152	151	152	°C
Residue		-	2	15	27	5	8	12	°C
Existent gum	ASTM D-381	-	5	0	0	0	0	0	mg/100 ml
Reid vapor pressure	ASTM D-323	45	69	305	268	256	25	248	kPa
Color	Visual	Green		Colorless	Yellowish	Yellowish	Yellowish	Yellowish	Visual
Appearance	TKI C-042	Clear		Clear	Clear	Clear	Clear	Clear	Visual

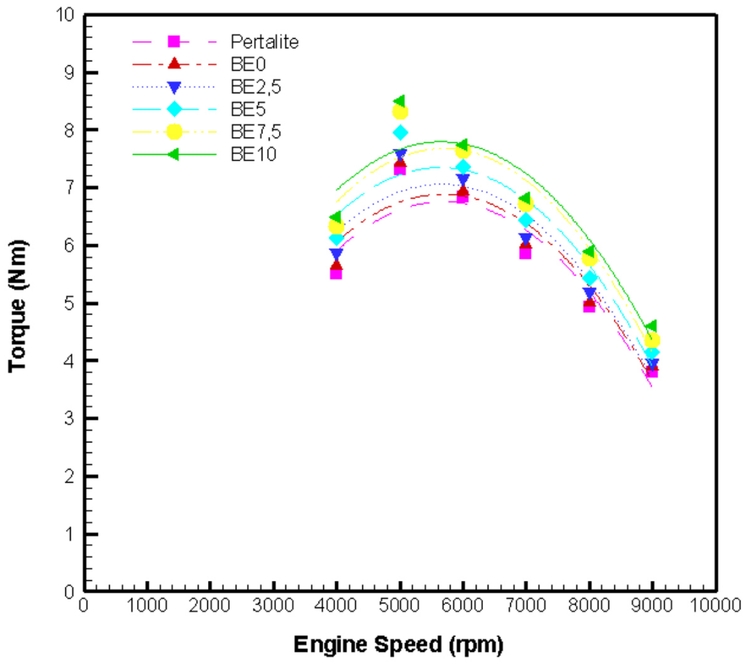

Figure 3. Torque variation with engine speed

other words, the remaining Fuel that has not been burned in the combustion chamber. It causes the work provided by the machine to be even more minor. The trend in this research results follows the research results of Arbiatara et al. The engine torque increases to a certain speed and reaches an optimum point (Arbiantara and Widodo, 2023; Xuan and Lim, 2019). The minimum torque produced by BE0 fuel is 7.44 Nm. at an engine speed of 5000 rpm. On average, a mixture of Fuel as much as 10% can increase engine torque by 2.5% compared to pure gasoline. The effect of engine speed on power and effective pressure when using various mixed fuels can be seen in Figure 4. The amount of motor power is proportional to the torque that occurs because this is related to the loading on the dynamometer chassis. The greater the load, the greater the torque that occurs. The influence of fuel composition on torque is also experienced using turpentine additives in diesel fuel (Robert et al., 2023). Theoretically, when the engine speed increases, the motor power will also increase because the power is the multiplication between torque and engine speed (El-adawy, 2023). Figure 5a shows that the specific fuel consumption (SFC) is an open upward curve. An

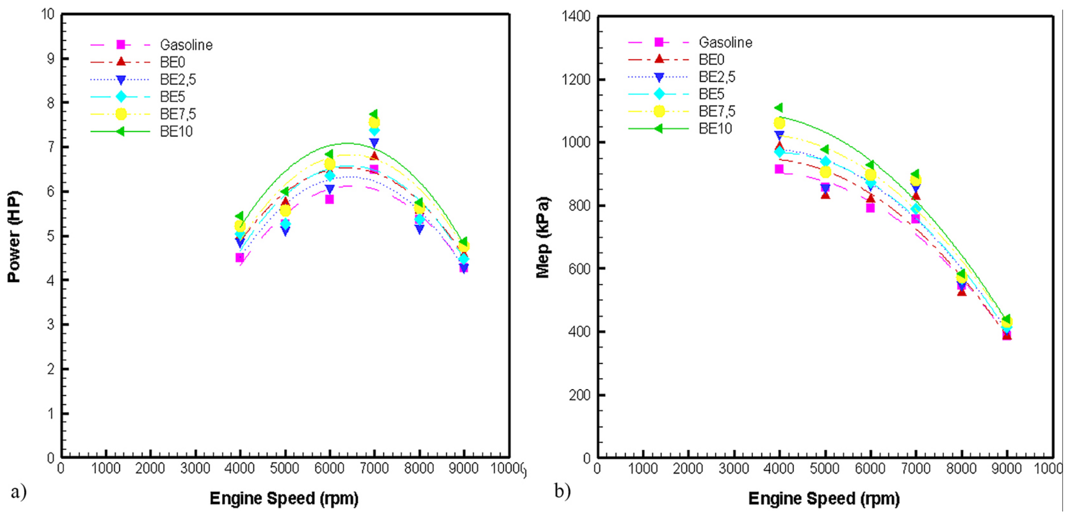

Figure 4. (a) Power variation with engine speed (b) effective pressure variation with engine speed

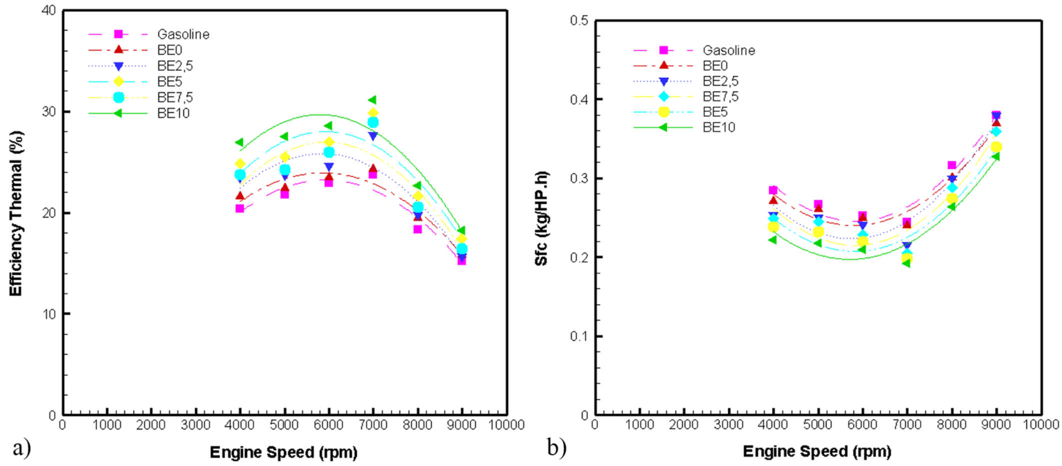

Figure 5. (a) Variation of SFC with engine speed (b) variation of thermal efficiency with engine speed

increase in engine speed at low speed causes the SFC to decrease until it reaches a minimum point. After that, SFC experienced a rise. The increase in SFC is due to better air and fuel flow turbulence and faster flame propagation. The SFC trend in this study is the same as the SFC trend in the use of ethanol-gasoline Fuel. At engine speeds higher than the optimum point, friction losses increase, and combustion perfection decreases. High engine speed reduces combustion time, automatically increasing the remaining unburned Fuel in the combustion chamber (Yang et al., 2023).

Figure 5(a) also shows that the composition of the mixed Fuel influences the SFC. BE10 blended fuel can reduce SFC compared to using BE0 blended fuel. Minimum SFC occurs in the BE10 fuel mixture at an engine speed of 7000 rpm (Siswanto et al., 2023). The average SFC reduction is 3% compared to commercial gasoline. Thermal efficiency measures the ratio of the power produced to the heat energy entering the engine. Figure 4b shows that the thermal efficiency forms an open downward curve. The highest thermal efficiency occurs at an engine speed of 7000 rpm. The use of BE10 mixed fuel is better than BE7.5–BE0 and commercial Fuel. The lowest thermal efficiency occurs when using BE0 fuel. The fuel blend can increase the engine's thermal efficiency by about 4.1% on average compared to pure BE0 gasoline. The results of this research differ from the trend of research on mixed fuels by adding ethanol to gasoline; increasing ethanol causes a decrease in thermal efficiency. Information on the influence of fuel composition and engine speed on SFC and thermal efficiency is the basis for optimizing combustion engine performance: low SFC and high thermal efficiency lower production costs. Figure 5b shows engine speed's effect on various mixed fuels' thermal efficiency. Thermal efficiency increases at low speeds up to 7000 rpm, then decreases at subsequent speeds. The highest thermal efficiency is 31.8% at a speed of 7000 rpm on BE10 mixed fuel. The thermal efficiency of this research is the best compared to the use of biodiesel blend fuel (Rahim et al., 2012), DE (Uyumaz, 2023), and ethanol-gasoline blend (Iodice et al., 2018; Manikandan & Walle, 2013).

CONCLUSION

The PDTO fuel blend specification has the advantage of being a biofuel type of gasoline with RON 91-97 and LHV 10.545–10.791 kcal/kg. PDTO fuel blend performance test results on various compositions and commercial fuels using a 4-stroke single-cylinder engine are better than the comparison commercial fuel. The research results show that engine torque, power and MeP are higher when using BE.5–BE10 blended fuel versus retail gasoline. The maximum torque that can be achieved is 8.51 NM at 5000 rpm using BE10 mixed fuel, higher than 6.81 NM for commercial fuel. The highest full power produced by BE10 fuel is 7.75 HP at an engine speed of 7000 rpm. Minimum power is produced by BE0 fuel, with a power of 6.78 HP at an engine speed of 7000 rpm. Optimal SFC occurs in the BE0 fuel mixture at 7000 rpm engine speed 0.25 kg/Hp·h. The thermal efficiency of BE10 reaches 31.8%.

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