



EXPERIMENTAL INVESTIGATION OF 2ND GENERATION BIOETHANOL DERIVED FROM EMPTY-FRUIT-BUNCH (EFB) OF OIL-PALM ON PERFORMANCE AND EXHAUST EMISSION OF SI ENGINE

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Abstract

The experimental investigation of 2nd generation bioethanol derived from EFB of oil-palm blended with gasoline for 10, 20, 25% by volume and pure gasoline were conducted on performance and exhaust emission tests of SI engine. A four stroke, four cylinders, programmed fuel injection (PGMFI), 16 valves variable valve timing and electronic lift control (VTEC), single overhead camshaft (SOHC), and 1,497 cm³ SI engine (Honda/L15A) was used in this investigation. Engine performance test was carried out for brake torque, power, and fuel consumption. The exhaust emission was analyzed for carbon monoxide (CO) and hydrocarbon (HC). The engine was operated on speed range from 1,500 until 4,500 rev/min with 85% throttle opening position. The results showed that the highest brake torque of bioethanol blends achieved by 10% bioethanol content at 3,000 to 4,500 rpm, the brake power was greater than pure gasoline at 3,500 to 4,500 rpm for 10% bioethanol, and bioethanol-gasoline blends of 10 and 20% resulted greater bsfc than pure gasoline at low speed from 1,500 to 3,500 rpm. The trend of CO and HC emissions tended to decrease when the engine speed increased.

Keywords: bioethanol, SI engine, performance, emission.

I. INTRODUCTION

Ethanol has been proposed and used as a fuel for vehicle engines since the 18th century [1]. Ethanol is the most suited fuel for spark-ignition (SI) engine with several advantages over gasoline, such as it can be produced from renewable energy source, it has better anti-knock characteristics, and the combustion resulting lower exhaust emission [2, 3]. It was reported that Henry Ford presented it as the fuel chosen for his automobiles during their earliest stages of development [1]. Due to the higher ethanol fuel grade production cost relative to gasoline, over several decades, the utilization of gasoline in spark-ignition engine is preferably.

Although the properties of ethanol is nearer to gasoline than diesel fuel, the research and development of ethanol utilization both for SI

and compression ignition (CI) engine have been carried out by many internal combustion engine researchers previously [3-28]. Physical and chemical properties of the fuel indicate its quality to be combusted in an engine, which influence performance and emission characteristics of the engine. A comparison between the properties of ethanol and gasoline is shown in Table 1. Due to its properties, ethanol can be used on SI engine without modification by blending it with gasoline to obtain lower concentrations of ethanol. Pure ethanol can be used in SI engines but some modifications to the engine is necessary [2, 29].

Al-Hasan [1] studied the effect of 99% purity ethanol-unleaded gasoline blends ranging from 0% to 25% with an increment of 2.5% on performance and exhaust emission of four stroke, 1,452 cm³, and 9:1 compression ratio Toyota SI engine. The results showed that 20% ethanol fuel blend gave the best results of the engine performance and exhaust emissions. Then, the

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addition of 25% ethanol to the unleaded gasoline did not give any problem during engine operation.

Bayraktar [29] used single-cylinder, four stroke and swept volume 763 cm³ SI engine, investigating performance and emission experimentally. The 93% purity of ethanol with the blends of concentrations 1.5, 3, 4.5, 6, 7.5, 9.1 and 12% (by volume) were used as fuels. The results showed that the most suitable blend for SI engines had been specified for 7.5% ethanol. From the emission analysis, the using of gasoline-ethanol blends in SI engines was dramatically reduced the CO concentrations.

Costa [30] investigated the influence of 10:1, 11:1 and 12:1 compression ratio of the four cylinders, eight-valves, and 1,000 cm³ flexible fuel engine on its performance using 22% ethanol blended in gasoline and 100% hydrous ethanol. The engine was operated in the speed range from 1,500 to 6,500 rev/min. The results showed that engine torque, brake mean effective pressure (BMEP) and output power substantially improved with the increasing of compression ratio at high speeds for both, E22 and hydrous ethanol. The specific fuel consumption of hydrous ethanol was higher than it of E22 in flexible fuel engine.

The combustion performance of bioethanol at various blend ratios in gasoline direct injection engine had been experimentally worked by Turner [24]. In this study when ethanol/gasoline blend increased from 0% to 100% compared with gasoline, the engine characteristics showed that efficiency increased and CO emission reduced.

Recently, the development of a clean, renewable and sustainable energy system has been started and became popular in many countries [31-40]. The depletion anxiety of fossil fuel source and increasing level of air pollution

caused by combustion of fossil fuel from transportation or industrial sector lead engineers and scientists to anticipate it. The one of popular developed renewable fuel is bioethanol. Bioethanol is produced from the fermentation of sugars obtained from biomass. Bioethanol feedstock can contain either sucrose (e.g. sugarcane, sugar beet) or starch (e.g. corn, wheat) or a lignocellulosic material (e.g. sugarcane bagasse, wood and straw, etc.) [33]. Since the ethanol is produced from these kinds of feed stocks it is called bioethanol. Bioethanol from sucrose or starch is known as 1st generation bioethanol, while bioethanol from lignocellulose is named as 2nd generation.

As mentioned in the literatures above, the utilization of ethanol in SI engine have been many reported. However, the utilization of ethanol derived from EFB of oil-palm in SI engine was not reported in literatures. Therefore, this study introduced EFB of oil-palm which is become great potential to be converted for the fermentative production of bioethanol due to its high cellulose content [31]. The aim of the study reported in this paper is to investigate the performance and emission of SI engine using bioethanol derived from EFB of oil-palm blended with gasoline varying from 0% to 25% by volume and engine speed from 1,500 to 4,500 rev/min. As has been reported that ethanol has 35% mass composition of oxygen, lower than bioethanol derived from EFB of oil-palm with 42.65% mass composition of oxygen [26, 41], therefore, bioethanol from EFB of oil-palm is suspected produces complete combustion on SI engine. The engine setup, experimental procedures, experimental results and finally conclusions are discussed in the following sections.

Table 1.
Properties of ethanol and gasoline [26]

Property	Ethanol	Gasoline
Chemical formula	C ₂ H ₅ OH	C ₄ -C ₁₂
Composition (C, H, O) (% mass)	52, 13, 35	86, 14, 0
Lower heating value (MJ/kg)	26.8	42.7
Density (kg/m ³)	790	715-765
Octane number ((R+M)/2)	100	90
Boiling temperature	78	25-215
Laten heat vaporization (25°C) (kJ/kg)	904	380-500
Self ignition temperature (°C)	420	≈300
Stoichiometric air/fuel ratio	9.0	14.7
Laminar flame speed @ 1 bar, 393K, Ø= 1.1 (cm/s)	≈63	≈52
Mixture calorific value (MJ/m ³)	3.85	3.75
Lower ignition limit in air (%vol)	3.5	0.6
Upper ignition limit in air (%vol)	15	8
Solubility in water at 20°C (ml/100ml H ₂ O)	fully miscible	<0.1

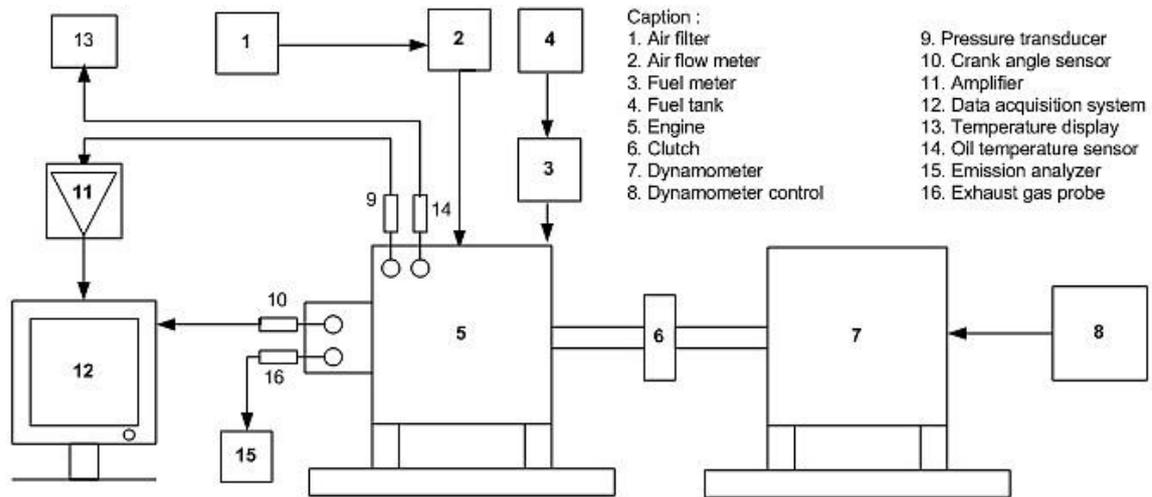


Figure 1. Schematic diagram of engine and instruments installation

II. EXPERIMENTAL SETUP

A. Engine and Instruments Installation

The performance and emission test were performed on a naturally aspirated, inline four cylinders and four stroke SI engine Honda L15A. The engine specification is shown in Table 2. The engine was coupled with eddy current dynamometer manufactured by Schenk, type W-70 with 70 kW maximum brake power of measurements. The dynamometer was equipped with control panel type LS-2010 fitted with torque gauge, proximity sensor tachometer and potentiometer to adjust or manage required load and speed. The dynamometer was also connected to water cooling system to release the heat resulted during the braking process. To monitor the temperature of oil, water coolant in the inlet and outlet of radiator, exhaust in the outlet manifold, engine block wall and cylinder head, several of K-type temperature sensors were attached on the related area of the engine.

The cylinder pressure was measured using water-cooled pressure transducer Kistler 6041A. This transducer was combined with DATAC

crank angle sensor attached on dynamometer shaft. To obtain IMEP value, the cylinder pressure signal and crank angle signal were processed in amplifier and data acquisition system Dewetron DEWE-2600-CA.

Fuel consumption was measured by using AVL fuel balance type 733S. The fuel balance was equipped with driver software RS733 which was installed in a personal computer. This software could be used to take certain data in once measurement process. Then the data were calculated automatically to obtain simple statistic analysis such as mean and standard deviation.

The air intake flow was measured by using hotwire anemometer DN50 from Technogerma system GmbH. The air flow meter was also equipped with thermometer to measure the air intake temperature. Both flowmeter and thermometer value could be observed on one display monitor by pushing the switch to change over. The exhaust gas emission was measured using portable emission analyzer Sukyoung GA-401. The schematic diagram of engine and instruments installation is shown in Figure 1.

Table 2.
Engine specification

Engine parameter	Basic data
Model/type	Honda L15A/four stroke SI
Fuel system	VTEC PGMFI
Air intake system	naturally aspirated
Cylinder/type	4/inline
Number of valve	16
Swept volume	1,497 cm ³
Bore x stroke	73 x 89.4 mm
Compression ratio	10.4:1
Max torque	143 Nm @ 4,800 rpm
Max power	81kW @ 5,800 rpm

B. Fuels Preparation

In this study, four fuel samples were investigated. A commercial gasoline called "Premium" produced by Pertamina Tbk was used as base fuel for the preparation of all blends and was named E0. 2nd generation bioethanol fuel grade at >99.5% purity, derived from EFB of oil-palm was produced and provided by Research Centre for Chemistry, Indonesian Institute of Sciences.

The specification of 2nd generation bioethanol derived from EFB of oil-palm was presented in Table 3. The gasoline was blended with ethanol to obtain three fuel blends i.e. 10%, 20% and 25% of total volume, named E10, E20 and E25. The fuel blends were prepared just before the experimental started to ensure the homogeneity and avoid extend reaction with air or water vapor.

C. Testing Procedure

The engine was started and operated in idle for about 15 until 30 minutes to warm up and ensure it in good condition. Then, the engine throttle was opened on 85% opening position. The engine load was adjusted through dynamometer control panel. The measuring loads were obtained by reducing the engine speed from 4,500, 3,000, 2,500, 2,000, and until 1,500 rpm. The engine parameters that were continuously recorded from each experiment included engine speed (rpm), brake torque (Nm), fuel consumption (kg/hour), oil temperature (°C), air mass flow (kg/hour), air temperature (°C), and IMEP (bar).

The room or environment condition test such as temperature (°C), pressure (mbar), and air humidity (%) were also recorded as supporting data. From the exhaust gas emission the content of CO (%), CO₂ (%) and HC (ppm) were measured, while, the parameters such as brake power (kW) and bsfc (g/kWh) were obtained from calculation of the recorded data. The following equations are formula for the calculation:

$$P = \frac{n \times T}{9549,3} \quad (1)$$

$$bsfc = \frac{\dot{m} \times 1000}{P} \quad (2)$$

where P is the power (kW), n is the engine speed (rpm), T is the engine torque (Nm), $bsfc$ is brake specific fuel consumption (g/kWh), and \dot{m} is fuel consumption (kg/h).

III. RESULTS AND DISCUSSION

A. Brake Torque

The effects of bioethanol-gasoline blends on engine brake torque at 1,500 to 4,500 rpm are shown in Figure 2. It can be seen that all the fuels had similar trends of brake torque. In other word, the brake torque characteristics of the engine were very similar when using pure gasoline compared to bioethanol-gasoline blends. Even though it has been reported that the ethanol addition decreased the heating value of gasoline[2], in this result there were no significant influence to engine brake torque. It may be explained that the bioethanol blends increased the oxygen content in the fuel and produced better combustion. But, it is possible that the octane number of the fuel blends not appropriate with the engine compression ratio. Therefore, the engine brake torque was not significantly influenced.

From the four types of fuels the highest brake torque was obtained at E25 when the engine was operated at low speed from 1,500 to 2,500 rpm. The opposite from that, at E25, when the engine was operated at high speed from 3,000 to 4,500 rpm the brake torque tended to decrease. The highest brake torque of high speed was obtained when engine operated using E10. The brake torque of E20 also decreased at high speed from 3,000 to 4,500 rpm.

B. Brake Power

The effect of bioethanol blends on brake power is illustrated in Figure 3. Generally, the brake power characteristics of the engine were

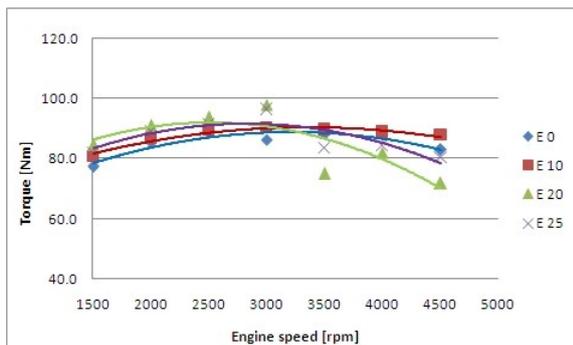


Figure 2. The effect of bioethanol blends on brake torque

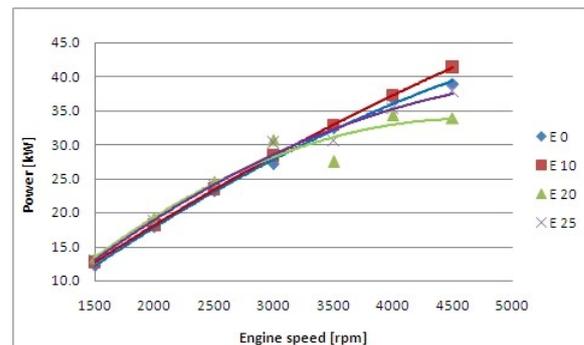


Figure 3. The effect of bioethanol blends on brake power

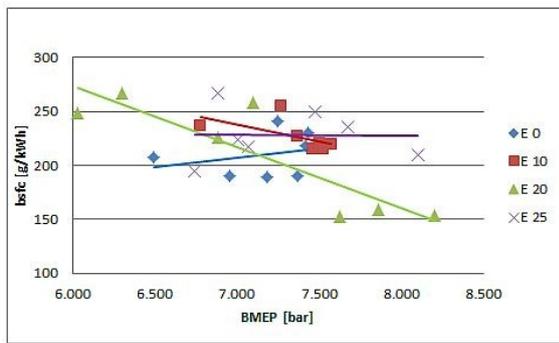


Figure 4. The effect of bioethanol blends on bsfc

similar when using gasoline compared to bioethanol blends. This behavior agreed with that of the brake torque shown in Figure 2. As shown in the figure, 10% ethanol-gasoline blends, E10, enhanced the engine brake power greater than gasoline at 3,500 to 4,500 rpm. Meanwhile, the E20 and E25 showed lower engine brake power than that of gasoline at 3,500 to 4,500 rpm.

The 10% bioethanol addition might be the optimal blend for increasing the brake power and be an appropriate blend for the engine compression ratio in this study. As explained by Bayraktar [29], ethanol addition to gasoline caused the engine operation leaner and improved engine complete combustion thereby, increasing the engine performance.

C. Bsfc

Figure 4 represents the effect of bioethanol blends on bsfc. The bsfc was calculated by divided fuel consumption measurement with brake power. It could be seen from the figure that at low speed from 1,500 to 3,500 rpm the bsfc of E10 and E25 were greater than that of pure gasoline E0. The results were in accordance with the finding of Koc *et al.* [2], where the lower energy content of ethanol-gasoline blends caused some increment in bsfc of the engine when it was used without any modification.

The increment mainly depended on the percentage of ethanol. Other reason could be explained by Bayraktar [29] that ethanol addition reduced the heating value of the bioethanol-gasoline blends, therefore, more fuel (by mass) was needed to obtain some power when blended fuels were used instead of gasoline. To produce same power at the same condition more blends were needed. The fuel consumption also depended on engine compression ratio. The higher engine compression ratio caused the lower fuel consumption. The bsfc of E20 increased at high engine speed from 3,500 to 4,500 rpm. Meanwhile, the bsfc of E10 and E25 decreased. It was possible that the bioethanol gasoline blends 20% suspected as optimal blends and appropriate

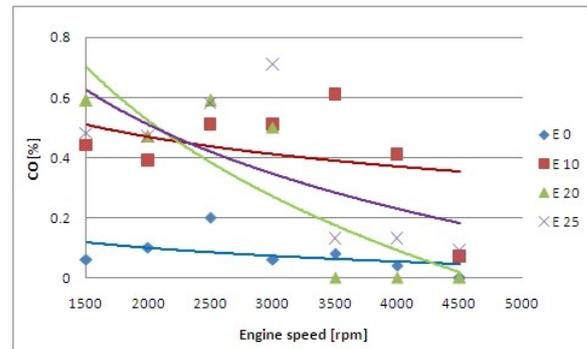


Figure 5. The effect of bioethanol blends on CO emissions

to be used for 10,4:1 engine compression ratio at high speed operation.

D. Carbon monoxide (CO)

Figure 5 shows the effect of bioethanol blends on the emission of CO. Even though the three bioethanol blends showed greater CO emission than gasoline, the CO emission trend tended to decrease when the engine speed increased. The better trend of CO was obtained from 20% ethanol-gasoline blends. It could be seen that the CO emission trend dramatically decreased when engine speed increased from 1,500 to 4,500 rpm. It was possible and could be predicted from the trend if the engine speed increased more than 4,500 rpm the CO emission from all fuel blends would be lower than that from pure gasoline. The CO content was always present in the exhaust gas even at lean mixture due to dissociation of fuel mixture[2].

The concentration of CO emissions was greatly depended on the operating condition of engine and air fuel ratio. The higher CO content at low engine speed might be caused by the lower charge temperatures in cylinder which could affect fuel vaporation and the lower CO content was achieved at high engine speed due to the higher charge temperatures obtained. This condition was in accordance with Venugopal study [26]. The other reason was explained by S.H. Yoon [28], that this might be due to the evaporation decreasing and the mixing of fuel under low temperature. Therefore, low temperature combustion depressed the hydrocarbon oxidization and created higher CO emissions.

E. Hydrocarbon (HC)

The effect of bioethanol blends on HC emission is shown in Figure 6. The trend showed that HC concentration of all fuel decreased when the engine speed increased. The HC concentration of bioethanol blends that was lower than pure gasoline occurred on E25. This might be resulted from leaning affect and oxygen

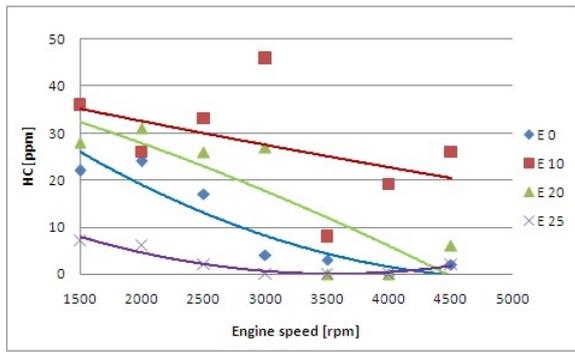


Figure 6. The effect of bioethanol blends on HC emissions

enrichment caused by bioethanol addition. The reason for the concentration reducing of HC emissions was that ethanol contains higher oxygen content in the fuel[28].

IV. CONCLUSION

In this paper, the experimental investigation of bioethanol derived from empty-fruit-bunch of oil-palm-gasoline blends for 10%, 20%, 25% and pure gasoline were conducted on SI engine. The results were obtained and concluded as follows:

1. The highest brake torque of bioethanol blends was resulted from 10% ethanol content at 3,000 to 4,500 rpm engine speed. It could be explained that the bioethanol blends increased the oxygen content in the fuel and produced better combustion at 3,000 to 4,500 rpm.
2. The 10% bioethanol-gasoline blends enhanced the engine brake power greater than gasoline at 3,500 to 4,500 rpm. The 10% bioethanol addition was possible suspected as optimal blends for increasing the brake power and was an appropriate blend for the engine compression ratio in this study.
3. Bioethanol-gasoline blends 10 and 20% at low speed from 1,500 to 3,500 rpm resulted greater bsfc than pure gasoline. It could be explained that the lower energy content of ethanol-gasoline blends caused some increment in bsfc of the engine when it was used without any modification.
4. The CO emission trend of bioethanol blends tended to decrease when the engine speed increased.
5. The HC concentration trend of bioethanol blends showed decreased when the engine speed increased.

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