Performance evaluation of four-wheel driving wheel tractor with diesel engine using biodiesel fuel

D A Sasmito 1, L T Mulyantara 2, A Budiman 1,3 *

1 Master Program in System Engineering, Universitas Gadjah Mada, 55281 Yogyakarta, Indonesia
2 Indonesian Centre for Agricultural Engineering Research and Development, 15338 Tangerang, Banten, Indonesia
3 Chemical Engineering Department, Universitas Gadjah Mada, 55281 Yogyakarta, Indonesia
*Corresponding author: abudiman@ugm.ac.id

Abstract. The Indonesian government is committed to increasing biodiesel usage as renewable energy by 23% of national energy consumption by 2025. Implementing the mandatory biodiesel program must be carried out sustainably to help reduce fossil energy consumption, reduce air pollution, and reduce the effect of greenhouse gases. The Ministry of Agriculture studied applying biodiesel from palm oil in agricultural machinery, especially four-wheeled tractors, to help implement agricultural mechanization in Indonesia. The research objective was to determine the effect of biodiesel on the performance of a four-wheeled tractor engine in several variations of the mixture to obtain the composition of biodiesel mixture that gave optimal engine performance. The experiment was conducted by testing the performance of a four-wheeled tractor engine on a laboratory scale referring to SNI 7146-2019, using biodiesel fuel with a mixture of B10 to B100 variations. The result showed that biodiesel affects the performance of a four-wheeled tractor engine. The efficiency of continuing engine power using biodiesel was the largest at B20 of 80.15% at the maximum governor and 80.97% at the standard PTO rotation of 540 rpm. The smallest power forwarding efficiency on the B100 was 76.12% at the maximum governor and 76.55% at 540 rpm PTO rotation. Biodiesel B20 provided the greatest maximum power of 23.55 kW, 44 kgf of torque, specific fuel consumption of 250.54 g/kW hours. At 540 rpm, PTO rotation produced a maximum power of 23.79 kW, 42 kgf of torque, the specific fuel consumption of 256.12 g/kW hours

1. Introduction

The increased use of biodiesel is a form of commitment from the Indonesian government to boost renewable energy use up to 23% of national energy consumption by 2025 [1]. The government has proclaimed the biodiesel utilization program since 2008 with the issuance of Regulation of the Minister of Energy and Mineral Resources of Republic of Indonesia Number 32 of 2008 on the mandatory use of business actors and encouraging the use of biofuels or Bahan Bakar Nabati (BBN) as a mixture of fuel oil (BBM). The implementation of the biodiesel mixtures has continued to increase, namely 2.5% in 2008, 20% in 2016, and 30% in 2020. The increased use of biodiesel is carried out sustainably to reduce petroleum imports, air pollution, greenhouse gas emissions, dependence on fossil energy, and increasing industrial production of palm oil and CPO [1]. The Indonesian government projects that the most extensive total GHG emissions in 2030 will come from the energy sector, which is 60% of total GHG emissions, followed by the forestry and agriculture sectors (27%), the waste sector (11%), and
Industrial Processes and Product Use (IPPU) sector (2%). The total emissions have increased 4 (four) times higher than in 2010 [1].

The Ministry of Agriculture supports government policies in biodiesel by conducting studies of biodiesel use on agricultural machinery. This activity is expected to strengthen the implementation of agricultural mechanization in Indonesia. The government continues to implement agricultural mechanization in the form of providing agricultural machinery and equipment to farmers. Based on data from Agricultural Statistics in 2019, the total assistance of two-wheeled tractors (TR 2) from 2015 to 2019 was 136,708 units, four-wheeled tractor engines (TR 4) from 2016-2019 amounted to 8,718 units [2]. Based on the application of biodiesel to agricultural machinery, the use of biodiesel can provide indirect benefits for farmers; they should not depend too much on fossil fuels.

Many studies on biodiesel development in Indonesia have been conducted. Research conducted by [3] reported that the development of biodiesel from research to commercialization as alternative energy in Indonesia was still very open. Infrastructure development, political and economic supports, and public trust could accelerate the use of biodiesel [4]. According to [5], which studied the quality specification of biodiesel B20 in a qualitative descriptive manner with purposive sampling technique, 19 main parameters of biodiesel used in Indonesia were produced. Another study, [6], reported that mixing diesel oil and biodiesel did not affect engine components such as engine injectors and fuel filters. Meanwhile, [7] stated that the splash technique of mixing biodiesel and diesel affected the filter components of a diesel engine.

Research on biodiesel production has also been conducted. [8] reported the biodiesel production by esterification process of Palm Oil Fatty Acid Distillate (POFAD) at a temperature of 70 °C with a 1% hydrochloric catalyst. Production by transesterification of oil palm with a heterogeneous catalyst obtained optimal results at a temperature of 60°C for 4 hours with an oil conversion of 62.51%. The research conducted by [9] reported that the optimal production of biodiesel from used cooking oil by transesterification occurred at a temperature of 66.5°C with an ester content of 97.76% with methanol as the reactant and KOH catalyst.

Several studies have been conducted on the effect of biodiesel on engine performance. A study conducted by [10] reported that the combustion of the Isuzu C233 diesel engine using biodiesel from oxidized bulk cooking oil mixed with B20 was better than diesel oil. Another study conducted by [11] reported that the maximum power of the Isuzu TFR 2500 DI pick-up with biodiesel was 4.6% lower. A 1-cylinder diesel engine at 1500 rpm engine speed with load variation using biodiesel from virgin coconut oil (VCO) with KOH and NOH catalysts affected engine performance and opacity [12]. In biodiesel formed from diesel oil in admixture with castor oil, [13] reported that a diesel engine with a mixture of B25 using the fuel open throttle valve method had an increased engine performance.

A study conducted by [14] reported that a tractor engine with a B100 endurance test showed that the engine performance had not decreased, but only the lubrication system had decreased its quality. The same result was also reported by [15] that the Kubota 14 Hp RT 140 diesel engine used for the fish pond aerator for 800 hours experienced a decrease in the lubricating oil quality. However, the engine performance was still within normal limits, and the reliability and mechanical resistance were maintained.

Most of the biodiesel research is applied to the transportation sector. However, it is still few in the agricultural sector. The purpose of the research is to apply biodiesel for agricultural machinery, especially for the performance of agricultural machinery.

2. Materials and method

2.1 Materials

The material used in this research is biodiesel B100 sourced from CPO and the comparative fuel for diesel oil and DEX produced by PT Pertamina. Biodiesel specifications are presented in table 1.
Table 1. Biodiesel specifications.

| Items                  | Specification          |
|------------------------|------------------------|
| Cetane numbers         | 57.1                   |
| Density at 40°C        | 867 kg/m³              |
| Viscosity              | 5.41 cSt               |
| Flashpoint             | 171 °C                 |
| Water and sediment     | 0 % - vol              |
| Total glycerol         | 0.2187 % mass          |

The tractor used for the performance test is of medium size with the specifications presented in table 2

Table 2. Tractor specifications.

| Item          | Specification                      |
|---------------|-----------------------------------|
| Drive type    | Diesel 4 stroke 3 cylinder        |
| Displacement  | 1647 cc                            |
| Maximum power | 39.4 hp (29.4 kW/2700 rpm)         |
| Aspirations   | Turbocharger                       |
| Fuel          | solar                              |

The process of preparing biodiesel fuel with variations of B10 to B100 begins with the mixing process. The mixing process is done manually according to the specified ratio. Then, stirring is done for 30 minutes to obtain fuel homogeneity.

The engine installation is done by setting up the fuel line from the fuel storage tank to the tractor fuel system. Then, the tractor’s Power Take-Off (PTO) shaft is connected to the PTO shaft of the dynamometer. After that, all sensors are connected to the control panel. The test installation is as shown in figure 1.

![Figure 1](image)

Figure 1. Testing installation: (1) tractor, (2) fuel tank, (3) thermocouple, (4) tractor gearbox, (5) load cell, (6) dynamometer, (7) compressor, (8) tachometer, (9) control unit, (10) PTO shaft.

This testing phase is carried out to determine engine performance with different fuel mixture variations. Performance testing is done in two ways; the maximum governor, which is the maximum engine speed, and standard PTO rotation of 540 rpm. The test loads the tractor gradually through the prony-brake PTO dynamometer from the compressor air pressure.
The load is given to the tractor until the maximum load, indicated by black smoke coming out and the engine nearly shutdown. Each time a load is given, the data of engine rotation speed, PTO shaft rotational speed, specific fuel requirements, engine temperature, transmission oil temperature, and room temperature are taken.

The data taken is then used to calculate the PTO output power (1), specific fuel consumption (2), and power transmission efficiency (3). From the calculation results, a graph of the relationship between maximum power and engine speed, a graph of the relationship between specific fuel needs and engine speed, and a graph of the relationship between torque and engine speed are made.

\[
Pt = \frac{Tpto \times n \times 2\pi}{60 \times 1000} \tag{1}
\]

\[
SFC = \frac{Fvl \times \gamma}{Pr.t} \tag{2}
\]

\[
\eta_t = 100 \times \frac{Pr.maks + Pt.maks}{Pr.motor} \tag{3}
\]

Where Pt is the output power of the PTO shaft (kW), Tpto is the shaft torque that supplies PTO swivel power (N.m), N is the rotational speed of the PTO shaft (rpm). SFC is the specific fuel consumption (gr/kW hours), fvl is the fuel consumption (ml/hours), Pr.t is the PTO shaft output power (kW), \(\gamma\) is the specific gravity of the fuel (g/ml), \(\eta_t\) is forward power efficiency (%), Pr max is the maximum output power (kW), Pt max is the maximum output power of the PTO shaft (kW) [16].

3. Result and discussion

3.1. Performance of Diesel Engines with Biodiesel Fuel at Maximum Governor

The results of the tractor performance test are the tractor engine performance indicated by the maximum power generated, specific fuel consumption, and torque at maximum power. The governor is carried out in the maximum test by adjusting the engine gas lever (throttle) to the maximum position to obtain maximum engine speed. The test results using biodiesel fuel with a mixture ratio of B10 to B100 for maximum power, specific fuel consumption, and the resulting torque are shown in figures 2, 3, and 4.

![Figure 2. Relationship between power and engine speed.](image-url)
The resulting values in several variations of the biodiesel mixture as in figures 2, 3, and 4 show that biodiesel B20 has the highest maximum power, 23.55 kW, specific fuel consumption of 250.54 gr/kW.hours, and 44 kgf of torque at 2340 rpm engine speed. Biodiesel B100 has the smallest maximum power, 22.37 kW, specific fuel consumption of 273.49 g/kW.hours, and 40 kgf of torque at 2417 rpm engine speed. The maximum power value produced is getting smaller with increasing biodiesel mixture ratio. Increasing the ratio of the mixture causes the viscosity of the fuel to increase. Consequently, the fuel injection process is less accurate because of the average diameter of the droplets increases. An inaccurate injection process results in an incomplete combustion process, and hence the power produced decreases [17]; [18]; [19]. A decrease in the resulting power causes the resulting torque to decrease. In addition, increasing the ratio of the mixture causes the calorific value of the fuel to decrease so that the energy content decreases [20]. This affects increased fuel consumption.

3.2. Performance of Diesel Engine with Biodiesel Fuel at PTO Rotation of 540 rpm

The performance of the tractor engine at the 540 rpm PTO rotation test is also shown by the maximum power produced, specific fuel consumption, and torque at maximum power. The performance test results are presented in figures 5, 6, and 7.
Figure 5. The relationship between power and engine speed.

Figure 6. The relationship between specific fuel and engine speed.

Figure 7. The relationship between torque and engine speed.

From figures 5, 6, and 7, the resulting engine performance shows the same pattern and results as the maximum governor test. Biodiesel B20 has the highest maximum power of 23.79 kW, the specific
fuel consumption of 256.12 g/kW.hour, and torque of 44 kgf which occurs at 2488 rpm. Biodiesel B100 has the smallest maximum power of 22.49 kW, the specific fuel consumption of 272.37 g/kW.hour, and torque of 40 kgf. The results show that the higher the ratio of the biodiesel mixture, the less the maximum power produced, the more the specific fuel requirements needed, and the less the torque produced. Several things that can affect the result of a decrease in engine performance include the increasing viscosity of the fuel, which causes the combustion process to be less than perfect because the average diameter of the fuel droplet spray increases, bad atomization, so that the injection that occurs is inaccurate [17]; [18]; [19]. The same result is also conducted by [20], where the increasing percentage of biodiesel mixture causes a low calorific value so that the energy content of the fuel decreases, and hence the loss of power increases.

3.3. Comparison of Engine Performance Test Results of Biodiesel Fuel B20, B30, B100, and Pertamina-Solar Fuel, DEX

This test is conducted to determine how much the difference in the performance of a tractor engine has when using biodiesel fuel compared to other fuels generally sold as products from PT Pertamina. The engine performance indicators used are maximum power, specific fuel, and the resulting torque. The test method used is the maximum governor and at 540 rpm PTO rotation. The results obtained are presented in table 3 and table 4.

Table 3. Performance Test at Maximum Governor.

| Fuel Types | Engine Rotation (rpm) | Maximum Power (kW) | Torque (kgf) | Specific fuel (g/kW.hour) |
|------------|-----------------------|--------------------|--------------|----------------------------|
| B20        | 2340                  | 23.55              | 44           | 250.54                     |
| B30        | 2581                  | 23.53              | 40           | 263.48                     |
| B100       | 2417                  | 22.37              | 40           | 273.49                     |
| Solar      | 2392                  | 23.82              | 44           | 254.89                     |
| DEX        | 2430                  | 23.26              | 42           | 261.77                     |

Table 4. Performance Test at 540 rpm.

| Fuel Types | Engine Rotation (rpm) | Maximum Power (kW) | Torque (kgf) | Specific fuel (g/kW.hour) |
|------------|-----------------------|--------------------|--------------|----------------------------|
| B20        | 2488                  | 23.79              | 42           | 256.12                     |
| B30        | 2359                  | 23.69              | 44           | 250.34                     |
| B100       | 2473                  | 22.49              | 40           | 272.37                     |
| Solar      | 2489                  | 23.88              | 42           | 253.93                     |
| DEX        | 2441                  | 23.44              | 42           | 262.98                     |

From table 3, it can be seen that the maximum power value for diesel fuel at 2392 rpm engine speed is 23.82 kW, the torque is 44 kgf, and specific fuel consumption is 254.89 g/kW.hour. Biodiesel B20 ranks second with a maximum power of 23.55 kW, 44 kgf of torque, and 250.54 g/kW.hour of specific fuel consumption. The smallest maximum power is biodiesel B100 which has a maximum power of 22.37 kW, a torque of 40 kgf, and specific fuel consumption of 273.49 g/kW.hour. There is a difference of 0.27 kW (1.13%) in maximum power between diesel oil and B20. The specific fuel consumption of B20 is less about 4.35 g/kW.hour (1.7%) than diesel oil. Compared with the DEX fuel type, the maximum power of biodiesel B20 is higher at 0.29 kW (1.2%). The fuel consumption of DEX is higher at 11.23 g/kW.hour (4.48%) than biodiesel B20. Furthermore, if biodiesel B30 is compared to diesel oil, the difference in maximum power produced is 0.29 kW (1.2%), and the specific fuel consumption is 8.59 g/kW.hour (3.37%).

From table 4, the test results at 540 rpm PTO rotation, it has been obtained that the greatest maximum power value for diesel oil is 23.88 kW, specific fuel consumption is 253.93 g/kW.hour, and
torque is 42 kgf. Biodiesel B20 is in second place with a maximum power of 23.79 kW, specific fuel 256.12 g/kW-hours, and torque 42 kgf. The smallest maximum power is biodiesel B100 with a maximum power of 22.49 kW, specific fuel consumption 272.37 gr/kW-hours, and torque 40 kgf. There is a difference of 0.09 kW (0.37%) between the maximum power of B20 and diesel oil. As for the specific fuel B20, the difference is higher at 2.19 gr/kW-hours (0.8%) than the diesel oil. Furthermore, if the B20 is compared to the DEX, the difference in maximum power produced is 0.35 kW (1.47%), and the specific fuel is 6.86 g/kW-hours (2.68%).

The results of engine performance with diesel oil are better than biodiesel. Three engine performance parameters, namely maximum power, torque, and specific fuel, show that the performance of diesel oil is higher than biodiesel. Fuel characteristics such as viscosity and calorific value can affect the engine performance. The viscosity of diesel oil is lower than that of biodiesel. The viscosity of diesel oil is 2-4.5 cSt, while the viscosity of biodiesel is 5.44 cSt. The calorific value of diesel oil is 43 MJ/kg, higher than the calorific value of biodiesel, which is 34-41 MJ/kg. The differences in the calorific value will affect the combustion process that occurs and the energy produced. Low viscosity will result in more complete combustion than high viscosity [17]; [18]; [19]. On the other hand, a low calorific value results in low fuel energy content so that the energy produced is low [18]; [20].

The suitability of fuel to engine specifications can also affect the resulting engine performance, and this happens to DEX fuel, which shows lower engine performance than biodiesel B20 and B30. DEX fuel has a high cetane number. Fuels of this specification are more suitable for use in engines with high combustion compression, such as diesel engines used in the transportation sector. This machine requires faster acceleration and produces a large amount of power at high engine speed. On the other hand, the diesel tractor engine has the characteristics of producing enormous power at low engine speed and does not require fast acceleration when operated. An engine with this characteristic is more suitable for using a low octane/RON number fuel because it is included in the low compression combustion criteria.

4. Conclusion
The use of biodiesel as a fuel mixture for diesel engines with several variations of the mixture influences the performance of four-wheeled tractors. The performance of a tractor engine using biodiesel is lower than that of a tractor using diesel oil. Biodiesel B20 provides the greatest engine performance result compared to other biodiesel blends. The lowest engine performance is produced when using biodiesel B100. Biodiesel can be used as an alternative fuel to replace fossil fuels.

5. Reference
[1] D. EBTKE 2020 Rencana Setrategis Direktorat Jenderal Energi Baru, Terbarukan dan Konservasi Energi 2020-2024, 1st ed. 1 (Jakarta: Dirjen EBTKE, Kementerian ESDM) Jakarta Pusat
[2] Pusdatin 2019 Statistik Sarana Pertanian Tahun 2018 Statistics of Agricultural Facilities, 2018. (Jakarta: Pusat Data dan Informasi Pertanian, Sekretariat Jenderal Kementerian Pertanian)
[3] Wirawan S S and Tambunan A H 2006 Third Asia Biomass Workshop pp. 1–15
[4] Suharta H 2007 Jurnal Ilmiah Teknologi Energi 1(3) 12–27
[5] Wibowo A, Febriansyah H, and Suminto S 2019 Jurnal Standardisasi, 21(1) 55
[6] Setyadi P and Wibowo C S 2015 JKEM UNJ, II(2015) 93–99,
[7] Sidjabat Dr O 2013 Lembaran Publikasi Minyak dan Gas Bumi, 47(1) 1–8
[8] Supranto, Purnomo, and Suhardi 2003 Proceeding International Seminar On Appropriate Technology for Biomass Derived Fuel Production 1(2003),
[9] Kawentar W A and Budiman A 2013 Energy Procedia, 32 190–199
[10] Aririwibowo D, Fadjar T K B, Suryo, M S K T 2011 Prosiding Seminar Nasional Sains Dan Teknologi Fakultas Teknik, 1(1) 91–96
[11] Suthisripok T and Ruechakiatdtkun T 2014 Adv. Mat. Res. 931–932(March) 1007–1014
[12] Bhikuning A 2014 Jurnal Energi dan Manufaktur 6(2) 123–128
[13] Widianoto A and Muhaji 2014 Jurnal Teknik Mesin 02(2014) 38–46
[14] Bietresato M and Friso D 2014 *Turk. J. Agric. For.* **38**(2) 214–223, doi: 10.3906/tar-1302-51.
[15] Suthisripok T and Semsamran P 2018 *Tribol. Int.* **128**(July) 397–409
[16] BSN and K T 65-04 2019 SNI 7416:2019 Traktor pertanian roda empat gandar ganda – Syarat mutu dan metode uji (Jakarta: BSN)
[17] Budiman A, Kusumaningtyas R D, Pradana Y S, and Lestari N A 2017 *BIODIESEL: Bahan Baku, Proses, dan Teknologi*. Kedua. (Yogyakarta: Gadjah Mada University Press)
[18] Ayhan D 2008 *Biodiesel “A Realistic Fuel Alternative for Diesel Engine*. (London, England: Springer)
[19] Kegl T, Kovač K A, Kegl M, and Kegl B 2013 *Green Diesel Engines*. (London, England: Springer)
[20] Li Y, Tian G, and Xu H 2013 Application of Biodiesel in Automotive Diesel Engines in Biodiesel - Feedstocks, Production and Applications University of Birmingham, UK