SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Evaluating the Performance of Agricultural Tractor Engine using Cottonseed Oil Biodiesel

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ARTICLE INFO

Article history:
Received 29 June 2024
Received in revised form 28 September 2024
Accepted 6 October 2024
Available online 20 October 2024

Keywords:
Renewable energy; biofuels; greenhouse gases; biodiesel; transesterification

ABSTRACT

The energy demand has been significantly increasing around the world in the last century. Conventional fossil fuels as one of the sources has been highly demanded due to its negative environmental effect. The growing demand for energy stimulated the development of renewable and eco-friendly alternative energy sources. Produced from vegetable oils and animal fats, biodiesel is a renewable, sustainable, and biodegradable fuel. It can be used as an alternate fuel to conventional diesel (CD) in compression ignition (CI) engines. The Belarus 920 tractor, with a maximum output of 74.5kW, was put through a Power Take Off (PTO) test in this study to assess its performance and emission components when fueled with conventional petroleum diesel, B20, B50, and B100 of Cotton Seed Oil Biodiesel (CSOME). The performance results showed that the power and Break Thermal Efficiency (BTE) fell, while the BSFC improved, when the tractor was fueled with neat CSOME and its mixes.

1. Introduction

As energy demand rises, petroleum fuel resources are becoming more scarce [1-3]. Following the oil crises of the 1970s, numerous non-oil producing nations started making attempts to reduce their reliance on fossil fuels by promoting the creation of alternative energy sources [4]. Among various energy resources, fossil fuels, particularly Conventional Diesel (CD) has been in high demand in the last century due to agricultural mechanization [5]. Primarily, the agricultural tractors that are powered by CI engines consume large quantities of CD and are the main source of greenhouse gases emitted during agricultural operations [6,7]. High levels of petroleum product usage have a detrimental impact on the environment, human health, and air pollution [8,9]. Additionally, the volatility of oil prices was a result of the rise in petroleum product usage and subsequent lack of traditional fossil fuels. The prevalence of alternative fuels has drastically increased due to these

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https://doi.org/10.37934/arfmts.122.2.181190

problems [10,11]. One of the sustainable alternative fuels, biodiesel is frequently made from animal and vegetable fats via a process known as transesterification [12,13].

Biodiesels can be used neat or blended with CD in a CI engine with minor modifications [14-16]. Among a broad range of biodiesels, cottonseed oil biodiesel (CSOME) is one of the most common biodiesels that has attracted much research works in the industry. Future alternative fuels for CI engines are anticipated to include CSOME [16]. Compared to other vegetable oils, cottonseed oil (CSO) is inexpensive to purchase [12]. When engines fueled with CSOME were evaluated by Fan *et al.,* [17], it was discovered that the CO and CO_2 emissions dropped when compared to CD and were at a standard that was approved by the American Society for Testing and Materials (ASTMD) 6751.

Al-lwayzy *et al.,* [18] conducted a PTO test utilising B20 of CSOME and CD by analysing the performance and emissions of the agricultural tractor John Deere 4410 tractor engine in the JD4410 Yanmar, 3TNE88, three cylinders water cooling diesel engine. The findings indicated that B20 of CSOME displayed a slightly greater gross energy than CD at low PTO torques (0–400 Nm) as a result of B20's higher fuel consumption (FC) rate in comparison to CD. Additionally, they discovered that B20's lower heating value and higher viscosity decreased the engine's BTE compared to CD. They also noticed that the B20 value's Brake Specific Fuel Consumption (BSFC) was higher than the CD at all loads. They also found that CO, CO_2 and NO_x increased with increasing PTO torque; however, the B20 of CSOME produced slightly a higher level of CO and CO_2. Shahid and Jamal [19] investigated CSOME in four strokes, three cylinders, DI, water cooled, CI engine. The exhaust line is related to a 5-gas exhaust gas analyzer (V402-01). They found that FC increased with the increasing ratio of CSOME in the blends.

This is related to the fact that combustion initiation gets challenging at larger biodiesel percentages (reference). Additionally, they noticed that BSFC declines with increasing load, which is a common feature of the engine. However, BSFC started to decrease as soon as the load exceeded 80%. Due to the reduced calorific value of biodiesel, they discovered that BSFC increased as the CSOME ratio in the fuel increased. Additionally, they discovered that the BTE begins to decline when the fraction of CSOME rises from B0 to B100. This was ascribed to insufficient time for heat transfer and inefficient fuel combustion. Additionally, Shahid and Jamal [19] reported that when an engine was fueled with CSOME as opposed to CD, CO and CO_2 emissions decreased by 40% and 22.13%, respectively. The primary factor for this decrease in CO is that biodiesel is an oxygenated fuel, and CSOME fuel contains fewer carbon atoms and a lower carbon to hydrogen ratio than CD. Contrary to CO and CO_2, NOx levels rise as the fraction of CSOME in the blends rises. This is due to the oxygen present in CSOME, which makes it easier for NOx to develop. For field tests, Li *et al.,* [20] employed CD and B100, B50, B20 generated from soybean oil as the fuel for farm tractors.

According to the findings, B20 performed fairly similarly to diesel in terms of FC and NOx emission. For B50 and B100 mixes, a greater FC and lower fuel economy were discovered. The biodiesel's decreased energy content is to blame for this. Compared to CD, NOx emissions were greater with B50 and B100, while CO_2 levels were significantly lower. In a 4-stroke, single-cylinder, water-cooled, normally aspirated, and direct injection (DI) diesel engine, Nabi *et al.,* [21] testing of CSOME. When the engine was fueled with a blend of B10, they discovered that smoke was decreased by 14% and PM by 24%. They also claimed that when the engine was fueled with B30, NOx increased by 10% and CO decreased by 24%. This study also discovered that the CSOME blends' lower heating value is to blame for the drop in engine BTE while utilising biodiesel. The BSFC values for CSOME mixes, as opposed to CD, saw an increase, nevertheless. This tendency was noticed because more biodiesel blends were needed to maintain a steady power output because they had a lower heating value than CD.

In a single cylinder, 4-stroke vertical, water-cooled, self-governed diesel engine operating at full load, Kale and Prayagi [22] employed CSOME, jatropha oil, and CD. According to the findings, blended CSOME had a slightly greater BTE than pure CSOME. The study also showed that using CSOME enhances the CI engine's performance metrics when compared to CD. Using CSOME and its blends (B5 to B100) in a single cylinder, 4-stroke, air-cooled diesel engine, Aydin and Bayindir [16] conducted PTO tests. Due to a higher viscosity and lower heating values of CSOME, they observed a decrease in power and an increase in BSFC for B100. For a lower proportion of biodiesel up to B20, however, no appreciable change in performance was noted. According to the study, CSOME's higher viscosity and lower heating values resulted in a decrease in the engine's BTE. The outcomes additionally demonstrated that all biodiesel blends exhibit lower CO and SO_2 emissions than CD. According to their findings, smoke emissions decrease for B50 and then increase for B75 to B100. Keskin *et al.,* [12] examined the CSOME fuel mixes in a single cylinder direct injection diesel engine.

Heavy operation circumstances were used to measure engine performances and different aspects of exhaust smoke. 1600 rpm was adjusted to 3000 rpm for the engine. The outcome demonstrated that when compared to CD, B40 and B60 engines produced slightly less power at higher engine speeds. Depending on the amount of biodiesel and engine speeds, the power loss ranged from 0% to 6.2%. According to the amount of biodiesel at maximum torque speeds, BSFC with CSOME blends increased up to 10.5%; nevertheless, smoke level of engine with blend fuels fell up to 46.6%. The biodiesel was combined with CD and utilised in CI engines in the majority of CSOME trials to assess performance and emissions. The Belarus 920 Tractor's performance and exhaust emissions were assessed using a PTO test in this study. In order to contrast pure CSOME with conventional petroleum diesel, the tractor was fueled with a B50 and B50 blend of CSOME.

2. Methodology

2.1 Tractor Test and Experimental Apparatus

The PTO test was conducted in this study using a Belarus 920 Tractor with a maximum power 74.5kW engine. Four cylinders, a 16:1 compression ratio, and a liquid-cooled cooling system make up the engine. The Nebraska test was used to evaluate this particular model of Belarus tractor. Figure 1 depicts the experimental configuration.

A manual volumetric fuel consumption measurement method was designed and used to measure fuel consumption in this study (Figure 1). The measurement method consists of two fuel tanks connected to 100 ml Buret via hosepipe line. The first tank is used for refilling the Buret, after fuel was fed into the engine while measuring the fuel consumption. The second tank was used as a main fuel tank for feeding the engine Tractor. Both fuel tanks were fitted with a three-way valve, which was placed in the main feed-in line of the tractor before the fuel pump. The over-flow fuel was returned to the Buret to obtain the net fuel consumption.

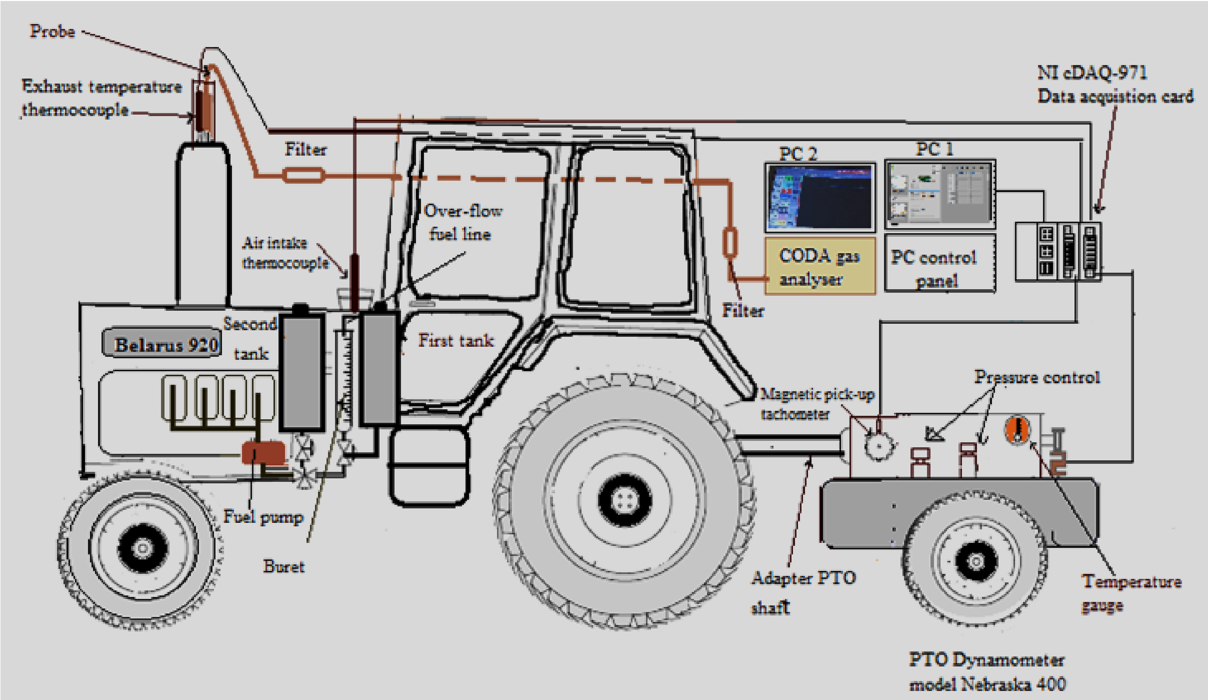

Fig. 1. Experimental setup

2.2 Dynamometer

The mobile PTO dynamometer from AW model Nebraska 400 shown in Figure 1 was used for applying various loads to the tractor. The main part of the PTO dynamometer is the friction-based brake system that produces torque. A hydraulic brake system was employed to apply the desired loads to the tractor accurately. The temperature of the brake system was kept steady at 75°C to ensure accurate measurement of produced torque. The temperature of water surrounding friction-based brake system was measured via gauge fixed on the side of the PTO dynamometer. A calibrated load cell was used to measure the produced torque by friction-based brake to ensure that desired load was applied to the tractor. A variety of instruments and sensors were used to measure different performance parameters of the tractor. The National Instrument data acquisition system (cDAQ-9174) was used to collect signals from thermocouples, load cells and tachometers.

2.3 Fuel Preparation and Properties

In this study, B20, B50 and B100 of CSOME and traditional petroleum diesel were used. CSOME was obtained from a local supplier. The specifications of the fuels used in this study are shown in Table 1. The B20 and B50 of CSOME were prepared in the laboratory of University of Southern Queensland (USQ). B20 was prepared by blending 20% of CSOME and 80% of traditional petroleum diesel by volume percentages, and B50 was prepared by blending 50% of CSOME and 50% of traditional petroleum diesel. The CSOME was manufactured from cottonseed oil (CSO) via Transesterification process. This process improves some properties of the biodiesel such as viscosity, molecular weight and volatility. In the transesterification process, methanol or ethanol were used as assistance substances in the presence of an alkaline catalyst, such as potassium hydroxide or sodium hydroxide to produce methyl or ethyl esters.

Table 1
Properties of traditional petroleum diesel, B20, B50 and B100 of CSOME

Properties	METHOD	Traditional petroleum diesel	B20 of CSOME	B50 of CSOME	B100 of CSOME
Lower calorific value MJ/kg	BS 2869	45.6	42.4	43.64	41.68
Density @ 15°C kg/m^3	ASTM D4052	830	846	870	910
Cetane Number	ASTM D4737	50	50.4	51.2	52
Flash Point °C	ASTM D93	66	70	110	160
Kinematic viscosity @ 40°C mm^2/s (CST)	ASTM D445	3.0	3.16	4.1	5

2.4 Test Procedure

The PTO test in this study was carried out using a PTO dynamometer. To assess the performance of the Belarus 920 Tractor, a dynamometer was mounted on it. Tractors were fueled with the B20, B50, and B100 of CSOME as well as conventional petroleum diesel. The tractor was operated under various loads—ideal, medium, and maximum—at various operating circumstances. All the fuels were evaluated in the same climatic circumstances, such as humidity, atmospheric pressure, and temperature, which are generally stable, in order to obtain accurate readings. Prior to the test, the tractor's engine was turned on and warmed up for 30 minutes. After warming up, the tractor was turned off and the PTO dynamometer was connected to the tractor via an adaptable shaft. The dynamometer was calibrated before it is attached to the tractor. A manual volumetric fuel consumption measurement system was fitted to the fuel feed equipped with an overflow fuel line. The tractor was switched on again and ran for five minutes on ideal operating condition to ensure the safety of the setup. The PTO shaft was run to power the PTO dynamometer. The speed of PTO drive shaft was increased to the maximum 588 rpm. The PTO torque was increased by dynamometer gradually on the tractor from 80 to 900Nm. The PTO speed was measured by a magnetic pick-up tachometer and the exhaust gases temperatures were measured through the thermocouple.

3. Results and Discussions
3.1 Output Power

Figure 2 shows the relationship between the PTO torque and output power traditional petroleum diesel, B20, B50 and B100 of CSOME. It can be seen from the figure that the output power of the tested fuels increased as PTO torque increased from 80 to 900 Nm. The increase of output power is mainly attributed to the increase of the torque as the decrease of the PTO speed was marginal. For example, when the torque was increased from 80 to 200 Nm (150% increase) for the traditional petroleum diesel, the PTO speed only dropped by 0.85% (from 588 to 583 rpm).

The output power of B20, B50, and B100 is, respectively, 1.25 percent, 3.0 percent, and 5.5% less than that of regular petroleum diesel under heavy-duty operating conditions (PTO torque of 500 to 900 Nm). This can be explained by the fact that tidy CSOME (like B100) has a calorific value that is around 10% lower than CD. These findings concur with those of Al-lwayzy *et al.,* [18] since both tests revealed an increase in the engine's braking ability as PTO torque rose. The findings of this investigation are in line with those of other studies, which showed that biodiesel fuel produces less power than CD [16].

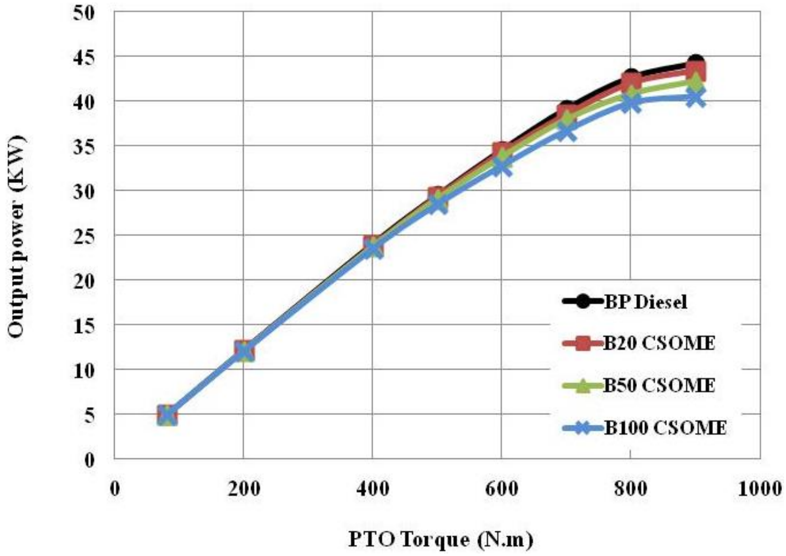

Fig. 2. PTO torques (Nm) versus output power (kW) for traditional petroleum diesel, B20, B50 and B100 of CSOME

3.2 Fuel Consumption (FC)

Figure 3 presents the change in fuel consumption with different ranges of PTO torque for the tested fuels. The figure illustrates that the FC steadily rose with increasing the PTO torque from 80Nm to 500 Nm for all tested fuels. As the PTO torque is increased from 55% to 88% (500-800 Nm), the FC rapidly increases for all fuels. This can be attributed to the lack of time for complete combustion. When PTO torque was increased from 800Nm to 900Nm, the increase of FC slowed down from 15.23 to 15.30 Kg/hr, 14.28 to 14.72 Kg/hr, 13.66 to 14.20 Kg/hr and 13.37 to 13.87 Kg/hr for B100, B50, B20 and BP diesel, respectively. The main reason is that the governor fully opened did not increase fuel flow rate to the engine to counterbalance power, and a high reduction occurred in PTO speed.

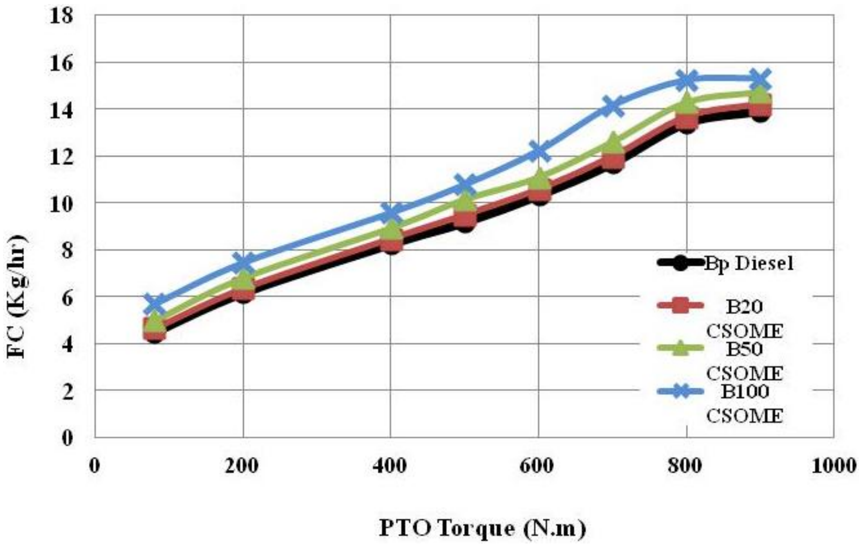

Fig. 3. PTO torques (Nm) against FC (Kg/hr) for traditional petroleum diesel, B20, B50 and B100 of CSOME

FC increased by 2.8%, 8% and 15% when tractor was fueled with B20, B50 and B100 of CSOME respectively compared to traditional petroleum diesel for all ranges of the PTO torque. This is due to the lower calorific values of the neat CSOME, and its blends compared to traditional petroleum diesel. The lower calorific value in COME causes a higher fuel flow rate consumption to generate the same power as that of traditional petroleum diesel [23]. A similar result was found by earlier studies [24,25].

3.3 Brake Specific Fuel Consumption (BSFC)

Figure 4 presents the BSFC of the tested fuels for PTO torque ranged from 80 to 900 Nm. The BSFC rapidly decreased from 0.907 to 0.341Kg/kW.hr for traditional petroleum diesel, 0.946 to 0.323 Kg/kW.hr for B20, 1.01 to 0.328 Kg/kW.hr for B50 and 1.157 to 0.373 Kg/kW.hr for B100 in the first half of the PTO torque, as shown in Figure 4. This is due to the increase of cylinder wall temperature that enhanced the combustion process.

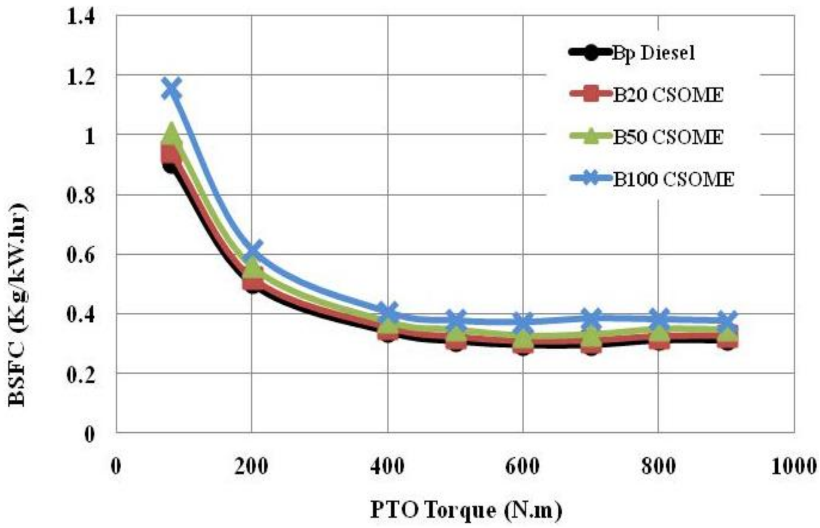

Fig. 4. PTO torques (Nm) vs. BSFC (g/hr) for traditional petroleum diesel, B20, B50 and B100 of CSOME

As PTO torque was increased from 400 to 600 Nm the reduction of the BSFC is insignificant, because the governor ruled out any compensation for power by pumping extra fuel. In the heavy operation conditions (600 to 900Nm) the value of the BSFC increased very slowly. This may be due to the practically constant FC in this PTO torque range and the considerable decrease in PTO speed, which both affect braking power. At all PTO torque levels, the BSFC of CSOME's B20, B50, and B100 was higher than that of conventional petroleum diesel by 4%, 10.2%, and 19.5%, respectively. For biodiesel with lower calorific values, such as B20, B50, and B100, additional FC is needed to keep a steady output power. This outcome is comparable to those mentioned by Özener *et al.,* [26] and Keskin *et al.,* [27].

3.4 Brake Thermal Efficiency (BTE)

The ratio of power produced to energy injected into the engine through fuel injection is known as brake thermal efficiency (BTE). Figure 5 shows the relationship between BTE and PTO torque for BP diesel, B20, B50, and B100 of CSOME. Figure 5 shows how the tested fuels' BTE changed for various torque ranges (80-900 Nm). According to Shahid and Jamal [20], increasing the torque improved combustion and decreased heat losses. Sahoo *et al.,* [5] and Reddy, *et al.,* [23] both reported similar outcomes. The chart shows that when PTO torque rose by 66% (from 80 to 600 Nm), BTE increased for standard petroleum diesel, B20, B50, and B100 of CSOME. This improvement in combustion and decrease in heat losses as torque rises may be the cause of the BTE's increase.

Figure 5 also illustrates that when the PTO torque increased from 600 to 900 Nm the BTE started to decline slowly. This might be attributed to the high reduction of the PTO speed and increase of FC (Figure 3). When the tractor was fueled with B100, B50 and B20, the BTE dropped by 23.9%, 18.9 % and 2.5%, respectively, as compared to traditional petroleum diesel for all PTO torque ranges. The lower calorific value and high viscosity and density of CSOME as well as its blends caused a reduction in BTE. This outcome is comparable with previous studies [28]. However, Keskin *et al.,* [27] studied the CSOME and its blends fuel and they observed that BTE of the engine increased with B20.

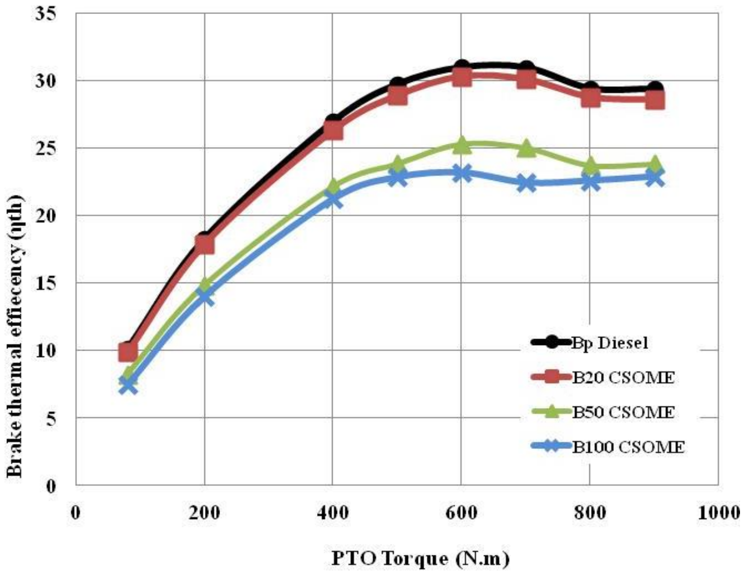

Fig. 5. Effect of PTO torques (Nm) on BTE (η_{th}) for traditional petroleum diesel, B50 and B100 of CSOME

4. Conclusion

In this study, Power Take off (PTO) test was conducted to evaluate the performance of Belarus 920 tractor. The result showed that the performance of the tractor decreased when fueled with CSOME and its blends. The result showed that power and BTE decreased, and the BSFC and FC increased when B20, B50 and B100 of CSOME were used, as compared to the traditional petroleum diesel. In addition to a slight decrease in engine performance and increased fuel consumption were observed. The experimental results found that the CSOME can be used as alternative fuel in CI engines and can produce comparable power.

Acknowledgments

The laboratory and the financial support by Faculty of Engineering, Koya University, Iraq and University Malaysia Pahang, Malaysia Al-Sultan Abdullah is gratefully acknowledged. The authors also extend their appreciation to the Deanship of Scientific Research at King Khalid University for supporting the project under grant number RGP.2/303/44.

References

[1] Bietresato, Marco, Carlo Caligiuri, Massimiliano Renzi, and Fabrizio Mazzetto. "Use of diesel-biodiesel-bioethanol blends in farm tractors: first results obtained with a mixed experimental-numerical approach." *Energy Procedia* 158 (2019): 965-971. https://doi.org/10.1016/j.egypro.2019.01.237
[2] Dwivedi, Gaurav, Siddharth Jain, and M. P. Sharma. "Impact of biodiesel and its blends with diesel and methanol on engine performance." *International Journal of Energy Science* 1, no. 2 (2011): 105-109.
[3] Demirbas, Ayhan. "Importance of biodiesel as transportation fuel." *Energy Policy* 35, no. 9 (2007): 4661-4670. https://doi.org/10.1016/j.enpol.2007.04.003
[4] Pillay, E., S. C. Fok, M. Elkadi, S. Stephen, J. Manuel, M. Z. Khan, and S. Unnithan. "Engine emissions and performances with alternative biodiesels: a review." *Journal of Sustainable Development* 5, no. 4 (2012): 59-73. https://doi.org/10.5539/jsd.v5n4p59
[5] Sahoo, P. K., L. M. Das, M. K. G. Babu, P. Arora, V. P. Singh, N. R. Kumar, and T. S. Varyani. "Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine." *Fuel* 88, no. 9 (2009): 1698-1707. https://doi.org/10.1016/j.fuel.2009.02.015
[6] Morón-Villarreyes, Joaquín A., Cristian Soldi, Alexandra M. de Amorim, Moacir G. Pizzolatti, Antonio P. de Mendonça Jr, and Marcelo G. M. D'Oca. "Diesel/biodiesel proportion for by-compression ignition engines." *Fuel* 86, no. 12-13 (2007): 1977-1982. https://doi.org/10.1016/j.fuel.2007.01.003
[7] Lindgren, Magnus, Gunnar Larsson, and P-A. Hansson. "Evaluation of factors influencing emissions from tractors and construction equipment during realistic work operations using diesel fuel and bio-fuels as substitute." *Biosystems Engineering* 107, no. 2 (2010): 123-130. https://doi.org/10.1016/j.biosystemseng.2010.07.010
[8] Ilkilic, C. "Exhaust emissions of a diesel engine operating by biodiesel fuel." *Energy Sources, Part A* 31, no. 15 (2009): 1415-1424. https://doi.org/10.1080/15567030802092775
[9] Pearce, Karen, Paul N. Holper, Mandy Hopkins, Willem J. Bouma, P. H. Whetton, Kevin John Hennessy, and Scott B. Power. *Climate Change in Australia*. Technical Report 2007. CSIRO Marine and Atmospheric Research, 2007.
[10] Wirawan, Soni S., Armansyah H. Tambunan, Martin Djamin, and Hiroshi Nabetani. "The effect of palm biodiesel fuel on the performance and emission of the automotive diesel engine." *Agricultural Engineering International: CIGR Journal* (2008).
[11] Şensöz, S., D. Angın, and S. A. İ. T. Yorgun. "Influence of particle size on the pyrolysis of rapeseed (Brassica napus L.): fuel properties of bio-oil." *Biomass and Bioenergy* 19, no. 4 (2000): 271-279. https://doi.org/10.1016/S0961-9534(00)00041-6
[12] Keskin, Ali, Metin Gürü, Duran Altiparmak, and Kadir Aydin. "Using of cotton oil soapstock biodiesel-diesel fuel blends as an alternative diesel fuel." *Renewable Energy* 33, no. 4 (2008): 553-557. https://doi.org/10.1016/j.renene.2007.03.025
[13] Mohamed, Mohamed Mokhatr, and Hossam El-Faramawy. "An innovative nanocatalyst α-Fe_2O_3/AlOOH processed from gibbsite rubbish ore for efficient biodiesel production via utilizing cottonseed waste oil." *Fuel* 297 (2021): 120741. https://doi.org/10.1016/j.fuel.2021.120741
[14] Canakci, Mustufa, and J. Van Gerpen. "Biodiesel production from oils and fats with high free fatty acids." *Transactions of the ASAE* 44, no. 6 (2001): 1429. https://doi.org/10.13031/2013.7010
[15] Kittur, M. I., Andri Andriyana, Bee Chin Ang, S. Y. Ch'ng, and M. A. Mujtaba. "Swelling of rubber in blends of diesel and cottonseed oil biodiesel." *Polymer Testing* 96 (2021): 107116. https://doi.org/10.1016/j.polymertesting.2021.107116
[16] Aydin, Hüseyin, and Hasan Bayindir. "Performance and emission analysis of cottonseed oil methyl ester in a diesel engine." *Renewable Energy* 35, no. 3 (2010): 588-592. https://doi.org/10.1016/j.renene.2009.08.009
[17] Fan, Xiaohu, Xi Wang, Feng Chen, Daniel P. Geller, and Peter J. Wan. "Engine Performance Test of Cottonseed Oil Biodiesel." *The Open Fuels & Energy Science Journal* 1, no. 1 (2008): 40-45. https://doi.org/10.2174/1876973X00801010040
[18] Al-lwayzy, Saddam H., Talal Yusaf, and Troy Jensen. "Evaluating tractor performance and exhaust gas emissions using biodiesel from cotton seed oil." In *IOP Conference Series: Materials Science and Engineering*, vol. 36, no. 1, p. 012042. IOP Publishing, 2012. https://doi.org/10.1088/1757-899X/36/1/012042
[19] Shahid, Ejaz Mehmood, and Y. Jamal. "Performance evaluation of a diesel engine using biodiesel." *Pakistan Journal of Engineering and Applied Sciences* (2011).
[20] Li, Y. X., N. B. McLaughlin, B. S. Patterson, and S. D. Burtt. "Fuel efficiency and exhaust emissions for biodiesel blends in an agricultural tractor." *Canadian Biosystems Engineering* 48, no. 2 (2006).
[21] Nabi, Md Nurun, Md Mustafizur Rahman, and Md Shamim Akhter. "Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions." *Applied Thermal Engineering* 29, no. 11-12 (2009): 2265-2270. https://doi.org/10.1016/j.applthermaleng.2008.11.009

[22] Kale, Bhojraj N., and S. V. Prayagi. "Performance analysis of cottonseed oil methyl ester for compression ignition engines." *International Journal of Emerging Technology and Advanced Engineering* 2, no. 8 (2012): 117-120.
[23] Reddy, N. Varun Kumar, S. G. Sangashetty, and N. R. Banapurmath. "Performance and emissions evaluation of diesel engine fueled with exhaust gas energy preheated CAOME biodiesel." *Materials Today: Proceedings* 45 (2021): 290-293. https://doi.org/10.1016/j.matpr.2020.10.649
[24] İlkılıç, Cumali, and Hüseyin Aydın. "Fuel production from waste vehicle tires by catalytic pyrolysis and its application in a diesel engine." *Fuel Processing Technology* 92, no. 5 (2011): 1129-1135. https://doi.org/10.1016/j.fuproc.2011.01.009
[25] Pillay, E., S. C. Fok, M. Elkadi, S. Stephen, J. Manuel, M. Z. Khan, and S. Unnithan. "Engine emissions and performances with alternative biodiesels: a review." *Journal of Sustainable Development* 5, no. 4 (2012): 59-73. https://doi.org/10.5539/jsd.v5n4p59
[26] Özener, Orkun, Levent Yüksek, Alp Tekin Ergenç, and Muammer Özkan. "Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics." *Fuel* 115 (2014): 875-883. https://doi.org/10.1016/j.fuel.2012.10.081
[27] Keskin, Ali, Metin Gürü, Duran Altiparmak, and Kadir Aydin. "Using of cotton oil soapstock biodiesel-diesel fuel blends as an alternative diesel fuel." *Renewable Energy* 33, no. 4 (2008): 553-557. https://doi.org/10.1016/j.renene.2007.03.025
[28] Canakci, Mustafa. "Combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel." *Bioresource Technology* 98, no. 6 (2007): 1167-1175. https://doi.org/10.1016/j.biortech.2006.05.024