Evaluating tractor performance and exhaust gas emissions using biodiesel from cotton seed oil

2012 IOP Conf. Ser.: Mater. Sci. Eng. 36 012042

(http://iopscience.iop.org/1757-899X/36/1/012042)

IOP Conf. Series: Materials Science and Engineering **36** (2012) 012042 doi:10.1088/1757-899X/36/1/012042

Evaluating tractor performance and exhaust gas emissions using biodiesel from cotton seed oil

Saddam H. Al-lwayzy[1], Talal Yusaf and Troy Jensen

National Centre for Engineering in Agriculture (NCEA), Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, 4350 QLD Australia.

E-mail[1]: SaddamHussen.Allwayzy@usq.edu.au, yusaft@usq.edu.au, Troy.Jensen@usq.edu.au

Abstract Alternative fuels for diesel engines, such as biodiesel, have attracted much attention recently due to increasing fuel prices and the imperative to reduce emissions. The exhaust gas emissions from tractors and other agricultural machinery make a significant contribution to these emissions. The use of biodiesel in internal combustion engines (ICE) has been reported to give comparable performance to conventional diesel (CD), but with generally lower emissions. There is however, contradictory evidence of NO emissions being both higher and lower from the use of biodiesel. In this work, agriculture tractor engine performance and its emission using both CD and biodiesel from cotton seed oil (CSO-B20) mixed at a 20% blend ration has been evaluated and compared. The PTO test results showed comparable exhaust emissions between CD and CSO-B20. However, the use of CSO-B20 led to reductions in the thermal efficiency and exhaust temperature and an increase in the brake specific fuel consumption (BSFC), when compared to CD.

1. Introduction

Interest in alternative fuels has increased substantially over the last decade as the demand for energy has intensified, whilst the reserves of fossil fuels are depleting. This has contributed to higher fuel prices making alternative fuels a viable commercial alternative. Enhancing the energy security is another factor for pushing towards alternative fuels to vary the sources of energy and also reduce the dependence on petroleum oil.

The diesel engine is widely used in most industries because of eht low fuel consumption and adequate efficiency [1]. Biodiesel is a viable alternative to conventional diesel as it is renewable, environmentally friendly and does not require significant modification to the existing diesel engine technology. For more than two decades, biodiesel has been used successfully in Europe and its use in the United State has increased considerably over recent years [1]. Raheman & Phadatare [2] concluded that Karanja biodiesel (with blend rates of up to 40% with conventional diesel) can be an alternative fuel for diesel engines. Recently, cotton seed oil and its methyl ester, are increasingly used in IC engines and it is expected to be one of the alternative fuels in the future [3].

Producing biodiesel from crops involves a series of steps in which diesel fuel is used. Using alternative fuel in agriculture is the first step for clean energy. As tractors are the major power source for most agricultural power consuming processes (e.g. tillage, loading, mower and tracking), investigating the potential of using biodiesel as the fuel source is a worthwhile exercise.

Sahoo et al. [4] tested the effect of different blend ratios of jatropha, karanja and polanga biodiesel when used in a three cylinder diesel engine. They found that there was raising corresponding increase in the Brake Specific Fuel Consumptions (BSFC) with the increase in the blend ratios. Industrially produced biodiesel and homemade biodiesel were tested in agricultural tractor diesel engine by Gravalos et al. [5]. The homemade biodiesel resulted same tractor performance as diesel fuel and give better performance than the commercial biodiesel. Therefore evaluating tractor engine performance and emissions is essential. Tractor power Take Off (PTO) test was conducted using conventional diesel (CD), Biodiesel from Cotton Seed Oil (CSO) 20% blended with 80% CD by volume, and microalgae Biodiesel (MB) 20% blended with CD under different PTO operation condition. In this work, the data of comparing the performance and emissions of CD and CSO-B20 at mid load was represented.

2. Materials and methods

2.1 Tractor test and experimental apparatus

The PTO tractor dynamiter test has been conducted using John Deere 4410 tractor ehydro (see Figure1). The engine in the JD4410 was a Yanmar, 3TNE88, three cylinders water cooling diesel engine with compression ratio of 18.8:1. The engine gross power is 25.8kW and the manufacture's estimated PTO power is 21.3 kW. The engine torque at rated speed is 87.9 Nm.

Figure 1. The experimental setup

2.2 Fuel consumption measurement

The fuel consumption rate was measured using the measuring cylinder shown in Figure 2. The measuring cylinder was fitted with a two-way valve at both the top and the bottom. The top two-way value allowed for the fuel returning from the injectors to either enter the cylinder or return to tank. The bottom two-way valve allowed for the fuel to either be drawn from the cylinder or to be supplied form the tank. In order to make a fuel consumption reading, the top and bottom value were open simultaneously allowing return fuel to enter the cylinder whilst fuel was being drawn from the bottom. A separate tank was connected when biodiesel was being used. The time was recorded using stop watch for fixed volume of fuel consumed. At the end of the test using CD, the system was cleaned and the fuel filter was changed to prevent any contamination from the previous test.

2.3 Dynamometer

PTO dynamometer was used on apply load to the tractor engine. The dynamiter was instrumented to measure PTO speed (rpm) and torque (Nm) and to calculate the power (kW). The instrumentation required that the dynamometer was calibrated after each series of tests. This calibration was conducted using five standard weights of 20 kg each. The calibration started by running the monitor of the dynamometer on the calibration mode. Then the zero torque was set. Then standard weights of 100 kg were suspended on an arm of one meter length to apply load on the load cell. At that time the torque of 981 Nm was set on the screen. The ratio of the engine to the PTO speeds was found to be 4.815.

2.4 Emission Analyser

A BEA 460 Bosch gas analyser was connected to the tractor exhaust to monitor the O_2, CO, CO_2, NO, and Lambda with the operating ranges and resolutions being given in Table 1. The gas analyser was calibrated by the manufacturer prior to the test.

Table 1. The gas analyser ranges, accuracy and resolution

Component	**Min.**	**Max.**	**Resolution**
CO (%)vol	0	10.00	0.001
CO_2(%)vol	0	18.00	0.01
HC (PPM)	0	9999	1
Lambda	0.5	22.00	0.001
NO (PPM)	0	5000	1

2.5 Thermocouple

A Digi-Sense thermocouple K type with four digit digital screen was used to monitor the exhaust gases temperatures with accuracy of 0.1%.

2.6 Fuel preparation

Pure CSO biodiesel (100%) was obtained from local supplier which has been converted to biodiesel though transesterification. The specifications of CSO biodiesel are given in Table 2. To prepare the CSO-B20 blend, 20% by volume CSO was mixed with 80% by volume of CD. The specification of CSO-B20 was calculated from the CD and CSO blend and is shown in Table 2.

Table 2. Properties of CD, CSO [1] and CSO-B20

Properties	**Diesel**	**CSO**	**ASTM method**	**CSO-B20**
Kinematic viscosity mm^2/s at 40^oC	3.9	6.0	D445	4.3
Density kg/m^3 at 15^oC	838	850	D1298	840.4
Higher calorific value kJ/kg	43.92	41.68	D5865	43.47
Cetane number	50	52	D613	50.4

Figure 2. The fuel measurement system

2.7 Engine test procedure

The test was conducted using different fuels of CD and CSO-B20 and MB-20 at different operating conditions of no load, medium load and maximum load. This work presents only the tractor performance and exhaust gas emissions results using CD and CSO-B20 for medium load operating conditions. In order to have consistence readings, the tests were conducted at same atmospheric conditions in which humidity, atmospheric pressure and temperatures are relatively constant. The tractor engine was warmed up for one hour before conducting the test using CD. The dynamometer was carefully calibrated using a standard calibration arms with different load and speed tachometer as mentioned in subsection 1.2 , this procedure was repeated three times to make sure PTO torques and speed readings are accurate. The test was performed by setting the tractor engine speed to 2000 (RPM) (without load) using the manual speed controller. This resulted in a PTO speed of approximately 415 rpm. Tests were conducted by increasing the load on the PTO, whilst engine speeds, PTO speeds, PTO torque and power, fuel consumption, exhaust temperature, and exhaust gas emission components was recorded simultaneously.

3. Results and disscussions

3.1 Tractor Engine Performance

The tractor PTO test was conducted to evaluate and compare the tractor performance using CD and CSO. The gross energy, brake power, brake specific fuel consumption, engine efficiency and exhaust temperature are presented below.

3.1.1 Gross energy and Brake Specific Fuel Consumption (BSFC)

The relationship between the gross energy and the PTO torque from CD and CSO-B20 is presented in Figure 3. The gross energy is the result of lower calorific value multiplied by the mass flow rate of fuel. Figure 3 shows that the gross energy increased over the PTO torque range between 100–400Nm. This energy rise was due to the high torque values associated with high engine speeds (1910-1710 RPM for CD and 1916-1705 RPM for CSO-B20) at this range of 100–400 Nm respectively. Figure 3 also shows that the gross energy started to decline after 400 Nm torque, caused by the engine speed reduction when higher torques were applied. The engine speed dropped to 1300 RPM for CD at 440 Nm and 1160 RPM for CSO-B20 at 430N. At PTO torques below 400 Nm, CSO-B20 shows a slightly higher gross energy than CD due to the higher fuel consumption rate of CSO-B20 compare to CD.

The BSFC is an indicator of fuel efficiency and is calculated by dividing the fuel consumption rate by the engine brake power. Figure 4 represents the relationship between the PTO torque and the BSFC for CD and CSO-B20. This figure shows a decrease in BSFC with PTO torque increases over the torque range from 100 Nm to 450 Nm. This result agrees with Forson, Oduro et al. [6] who found that increasing the engine torques will decrease the BSFC for all fuel blends of diesel and Jatropha biodiesel. The results presented in Figure 4 showed that the BSFC value of CSO-B20 is higher than the CD at all loads. The maximum BSFC for CSO is 644 g/kwh at 100 Nm, while the maximum BSFC for CD is 574 g/kwh at around 100 Nm PTO torque. The reason of this reduction is due to the lower calorific value of the CSO which means the engine started to consume more CSO-B20 to produce same power.

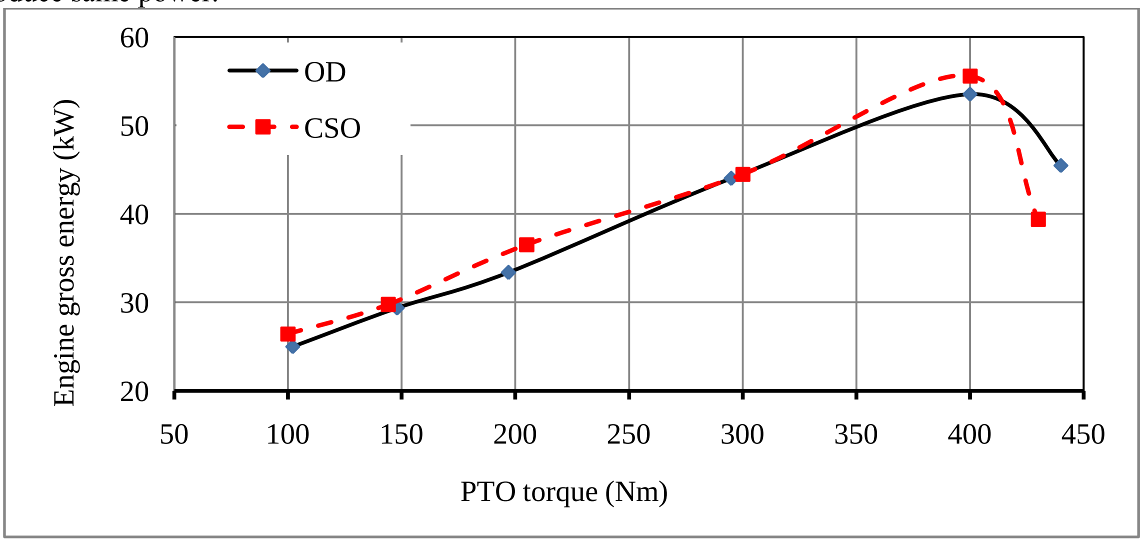

Figure 3. The relationship between PTO torques (Nm) and engine gross power (kW) for CD and CSO-B20

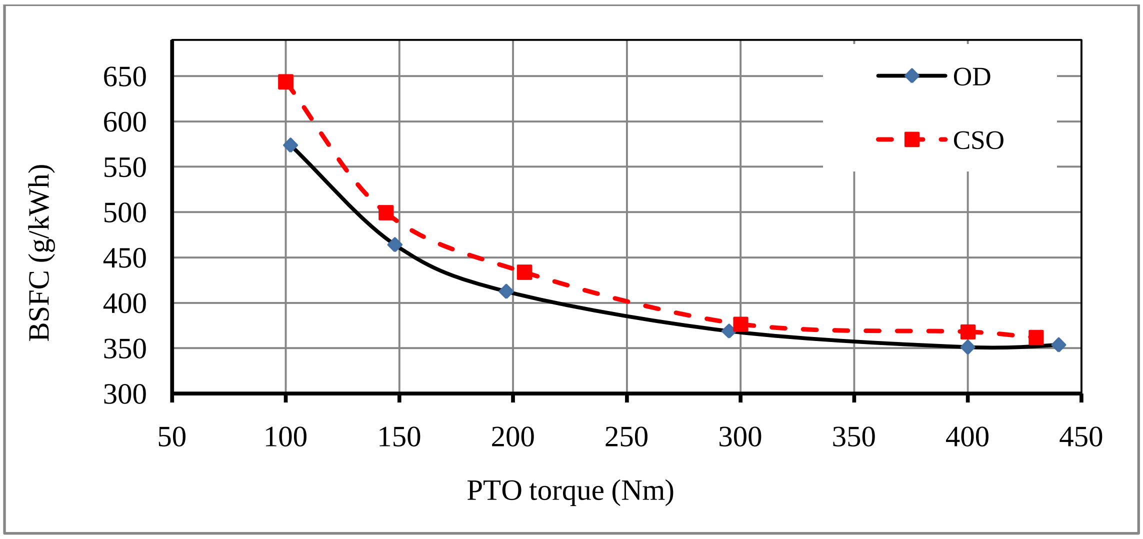

Figure 4. The relationship between PTO torques (Nm) and BCFC (g/kWh) for CD and CSO-B20

3.1.2 Engine Brake Thermal Efficiency (ηth)

Figure 5 represents the relationship between the PTO torques and the engine brake thermal efficiency (η_{th}) at medium loads. Figure 5 shows that that the brake thermal efficiency of both fuels was noticed to be increasing with the increase of PTO torque. Same trend was found by [2] in which, the thermal efficiency increased with torque increased, the reason for that was due to the power gain and the reduction in heat losses as torque increase. As discussed previously, the gross energy of CSO is higher than CD at same brake power, therefore a reduction in thermal efficiency of CSO-B20 occurred at all PTO torques. Nabi et al. [1] reported that the reduction in the engine thermal efficiency using biodiesel is due to lower heating value of the biodiesel (cotton seed blends). Aydin & Bayindir [3] stated that the higher viscosity and lower heating value of biodiesel of cotton seed oil cause a reduction on the engine efficiency in comparison with diesel. Those outcomes show an agreement with the outcome of the thermal efficiency of the present work.

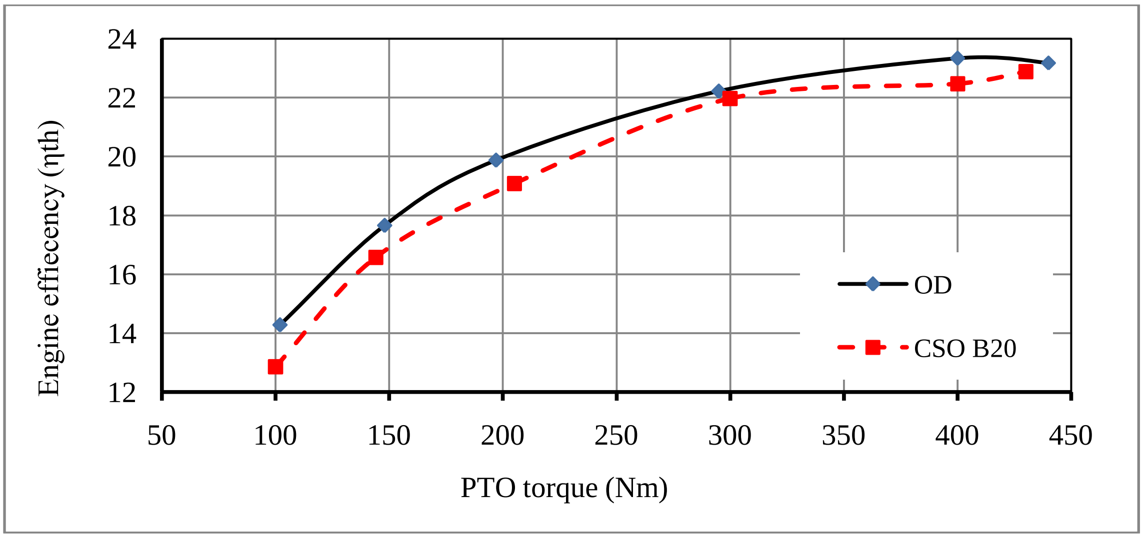

Figure 5. The relationship between PTO torques (Nm) and engine brake thermal efficiency (η_{th}) for CD and CSO-B20

3.1.3 Exhaust Temperature

Figure 6 draw the relationship between the PTO torques and the exhaust gas temperature for CD and CSO-B20. This figure shows an increase in the exhaust temperature with the increasing of PTO torques for both fuels, that is until the maximum temperature is reached at 400 Nm, and then the exhaust temperature goes down at the maximum studded torque. The maximum exhaust temperatures are 450 ^oC and 439 ^oC for CD and CSO-B20 respectively. The general trend of exhaust temperature for the engine fuelled by CSO-B20 is found to be lower than the exhaust temperature when the engine fuelled by CD. The possible reason for that difference in the exhaust temperature is due to the lower adiabatic flame temperature for the CSO-B20 than diesel.

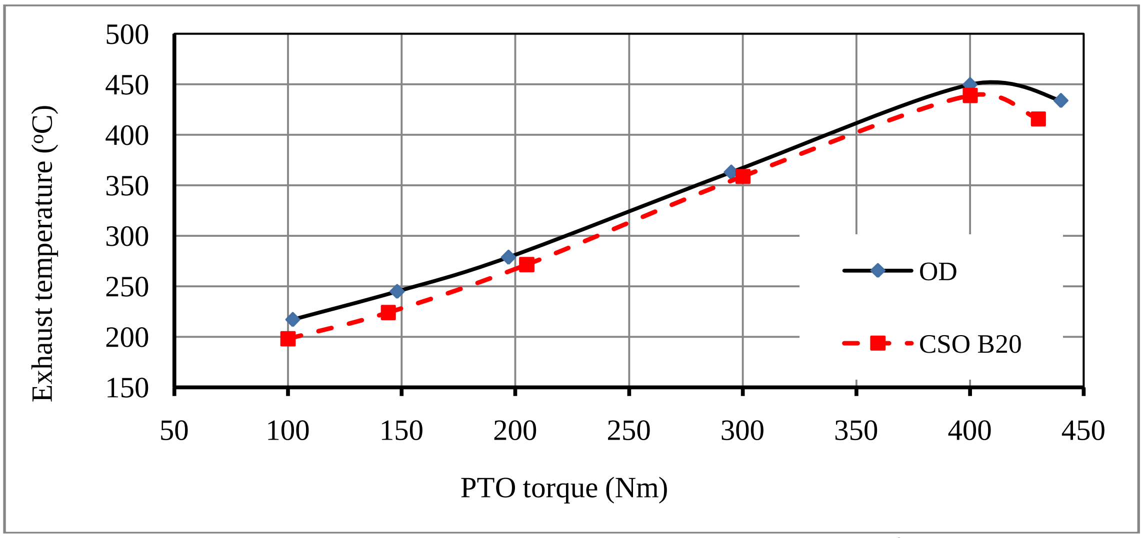

Figure 6. The relationship between PTO torques (Nm) and exhaust temperature (^oC) for CD and CSO-B20

3.2 Engine Gases Emissions

3.2.1 Carbon Monoxide (CO) and Carbon Dioxide (CO_2)

Excess CO concentration in the exhaust gas means the reactions in the combustion chamber is incomplete. The CO emission measured in percentage versus the PTO torques using CD and CSO-B20 is presented in Figure 7. This figure shows that the CO percentage at the toques below 300 Nm is almost constant, while the CO percentage at the torques above 300 Nm increased sharply for both fuels. Both fuels give comparable results at the PTO torques below 400 Nm because of the lean combustion indicated by the Lambda values in Figure 11. This Lambda results show that and amount of oxygen is higher than the stoichiometric for both fuels. On the other hand, CSO-B20 shows higher CO level than CD at the torque up to 400 Nm.

Figure 8 displays the CO_2 percentage against the PTO torques for CD and CSO-B20. It can be seen that the CO_2 level increase with the PTO torque increase for both fuels. CSO-B20 produces CO_2 level slightly higher than CD for the torques below 300 Nm. This results agree with Murugesan et al. [7] outcome in which, there were no significant effect of vegetable biodiesel B20 on CO_2 concentration in the exhaust gas emission.

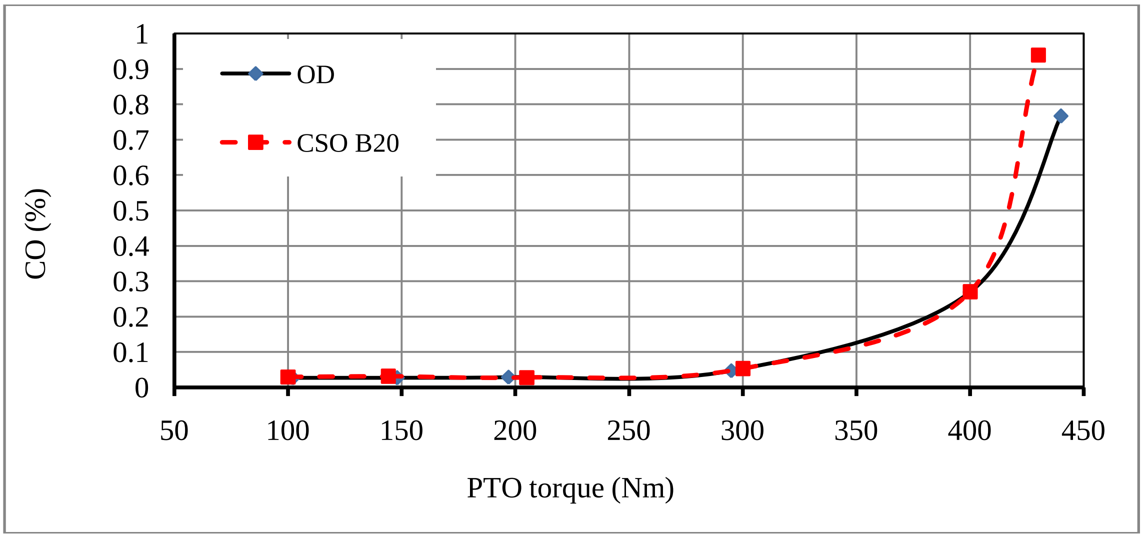

Figure 7. The relationship between PTO torques (Nm) and CO (%) for CD and CSO-B20

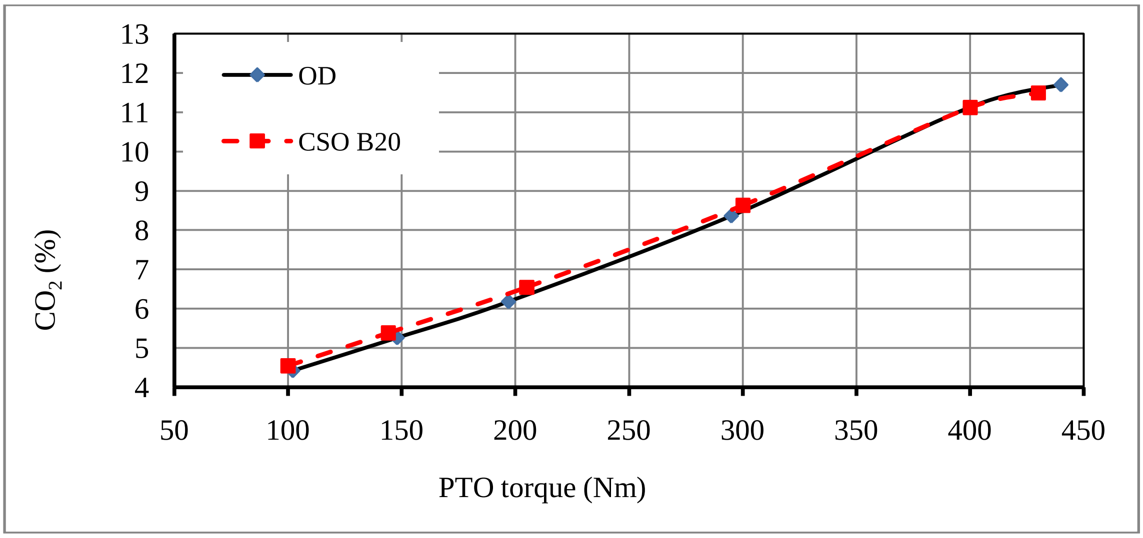

Figure 8. The relationship between PTO torques (Nm) and CO_2 (%) for CD and CSO-B20

3.2.2 Nitrogen Monoxide (NO)

The relationship between the level of NO (PPM) and the PTO torque is given in Figure 9 for CD and CSO-B20. The general trend of both fuels shows that increasing the PTO torque led to an increase in NO concentration (measured in PPM). The NO rise can be due to higher loads and exhaust temperature. Murugesan et al. [7] results showed a reduction in NO with the percentage of biodiesel increased for different engine load. This results show that there was no considerable difference between diesel and B20 of vegetable oil.

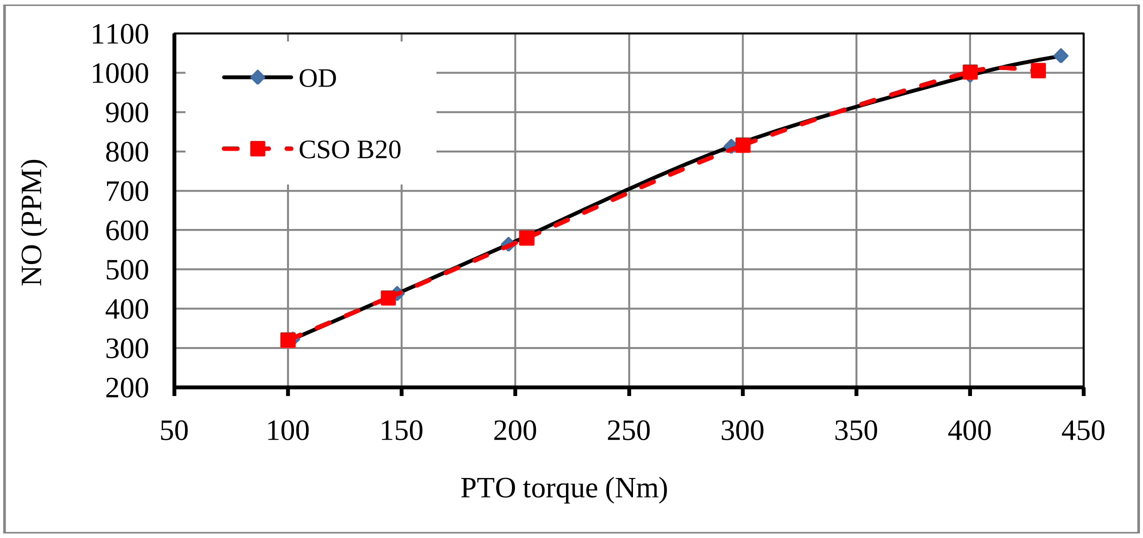

Figure 9. The relationship between PTO torques (Nm) and NO (PPM) for CD and CSO-B20

3.2.3 Oxygen (O_2) and lambda (λ)

Figure 10 represent the relationship between the PTO torque and the O_2 level for CSO-B20 and CD. This figure shows a decline in O_2 percentage from 14.7% and 14.4% to 3.6% and 4.5% for CD and CSO-B20 respectively at different PTO torque values. The O_2 percentage was found to be comparable between CSO-B20 and CD at all PTO torques.

The relationship between lambda and the PTO torques for CD and CSO-B20 is shown in Figure 11. Lambda is the actual air-fuel ratio divided by the stoichiometric air-fuel ratio. When Lambda is higher than one, the engine runs lean, which is a normal case in diesel engines [8]. Figure 11 shows that both fuels are running lean over different PTO torques. The lambda's values were noticed to be decreased with decreasing the load applied on the engine for both fuels. This reduction is a result of high fuel requirement to produce more power. Andersson [9] reported that diesel engines run lean at ideal and low load because of the air flow is constant while the fuel can be controlled through acceleration. The results presented in this work showed good agreement with Andersson [9] results.

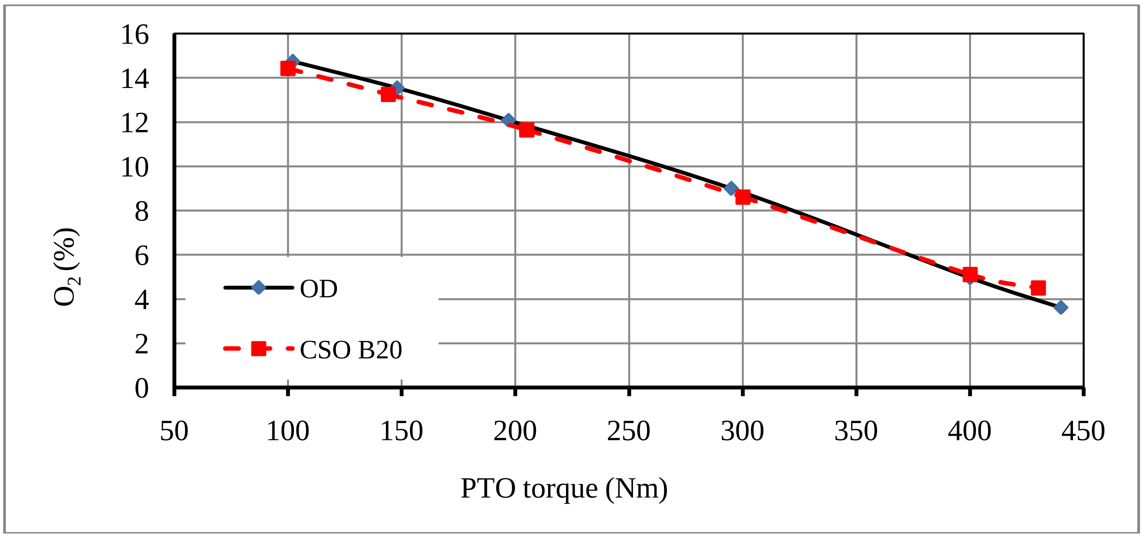

Figure 10. The relationship between PTO torques (Nm) and O_2 (%) for CD and CSO-B20

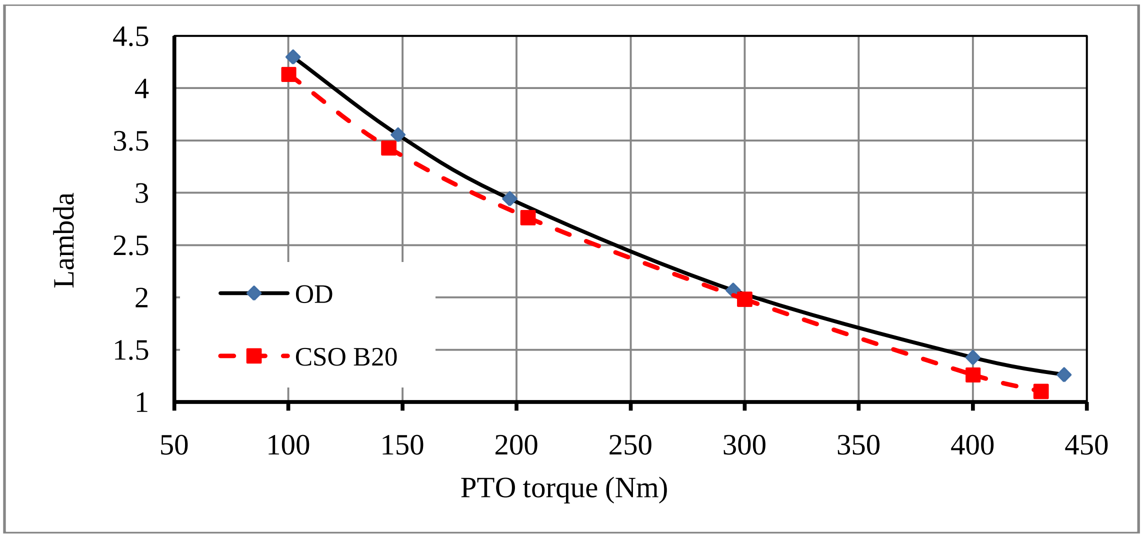

Figure 11. The relationship between PTO torques (Nm) and lambda (λ) for CD and CSO-B20

4. Conclusion

The medium load engine test results demonstrated that biodiesel from cotton seed oil can be a good alternative fuel for diesel engine at B20 blend without engine modification. It was found that CSO-B20 can produce very comparable engine performance and exhaust gas emission results at medium load. The experimental results showed CSO-B20 produce higher BSFC and lower engine thermal efficiency in comparison with CD across a wide range of PTO torques. Further experimental work is needed to investigate the affect of different blend ratio on engine performance and exhaust gas percentage.

References

[1] Nabi, M.N., M.M. Rahman, and M.S. Akhter, *Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions.* Applied Thermal Engineering, 2009. **29**(11-12): p. 2265-2270.

[2] Raheman, H. and A.G. Phadatare, *Diesel engine emissions and performance from blends of karanja methyl ester and diesel.* Biomass and Bioenergy, 2004. **27**(4): p. 393-397.

[3] Aydin, H. and H. Bayindir, *Performance and emission analysis of cottonseed oil methyl ester in a diesel engine.* Renewable Energy, 2010. **35**(3): p. 588-592.

[4] Sahoo, P.K., et al., *Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine.* Fuel, 2009. **88**(9): p. 1698-1707.

[5] Gravalos, I., et al., *Comparison of performance characteristics of agricultural tractor diesel engine operating on home and industrially produced biodiesel.* International Journal of Energy Research, 2009. **33**(12): p. 1048-1058.

[6] Forson, F.K., E.K. Oduro, and E. Hammond-Donkoh, *Performance of jatropha oil blends in a diesel engine.* Renewable Energy, 2004. **29**(7): p. 1135-1145.

[7] Murugesan, A., et al., *Bio-diesel as an alternative fuel for diesel engines--A review.* Renewable and Sustainable Energy Reviews, 2009. **13**(3): p. 653-662.

[8] Fernando, S., C. Hall, and S. Jha, *NOx Reduction from Biodiesel Fuels.* Energy & Fuels, 2005. **20**(1): p. 376-382.

[9] Andersson, C., *Observations on Electric Hybrid Bus Design*, in *department of Industrial Electical Engineering and Automation*. 2001, Lund Institute of Technology: Lund. p. 117.