Effect of Fuel Properties of Cottonseed Oil Biodiesel on the Performance of Diesel Engine

*Aliyu G. Alhassan and Abubakar B. Aliyu

1Department of Mechanical Engineering, Bayero University, Kano, Nigeria
aliyugaladi@yahoo.com | abaliyu.mec@buk.edu.ng

Abstract - This paper presents a study on the effect of fuel properties of cottonseed oil biodiesel on the performance of a diesel engine. The fuel properties of a biodiesel determine its effect on the performance of a diesel engine and perhaps, the degree at which it could be considered as a good alternative to the conventional diesel (petro-diesel). In this study, three biodiesel samples were produced from cottonseed oil via transesterification process using three different catalysts (NaOH, CaO, and Nano-CaO), i.e. using single catalyst per sample. The biodiesel samples (denoted by B-NaOH, B-CaO and B-Nano-CaO) were characterized and found to have some differences in their fuel properties. The biodiesel samples (100%) and petro-diesel (for comparison) were tested on a single cylinder Viking Super 165F diesel engine to determine the effects of their properties on performance of the engine. The test results showed that the biodiesel samples gave higher brake thermal efficiencies and higher brake specific fuel consumption compared to petro-diesel at virtually all loads. The results also indicate that B-NaOH biodiesel sample has the highest brake thermal efficiency and lowest brake specific fuel consumption among the biodiesel samples tested.

Keywords - Biodiesel, Catalysts, Cottonseed oil, Diesel Engine, Fuel properties, Transesterification

1 INTRODUCTION

Renewable and environmental friendly energy resources have gained significant attention due to increased focus on global warming and depletion of non-renewable energy resources like the fossil fuels (Refaat, 2011). Amongst all the fossil fuels used, diesel fuel is being considered as the most commonly used in the area of transportation, manufacturing industries and agricultural machineries (Jordan et al., 2017). As the demand for these fuels is increasing, it could lead to the depletion of limited petroleum reserves and unavoidably increase the price of petroleum products. Therefore, the development of alternative fuels is highly recommended in order to extend the estimated depletion period of the fossil fuels and also, to provide long term energy security. The most promising alternative to the conventional diesel fuel is the biodiesel. Biodiesel, which is synthesized from vegetable oil, is a realistic alternative to conventional diesel fuel since it is produced from renewable resources (Feedstock) and create less exhaust emission of harmful gasses and also, contains no polluting chemicals like sulfur (Meisam et al. 2015).

There are more than 350 oil bearing crops that have been identified, among which only sunflower, soybean, cottonseed, mango seed, rapeseed and peanut oils were considered as potential feedstock for biodiesel production (Vijayaraj, 2014). In this study, cottonseed oil was selected due its good properties, availability and economic potentials in Nigeria. Cottonseed oil is mostly not preferred as edible and its demand in the food industry is diminishing because of the health problems linked to its consumption. Cottonseed oil is the only important oil in the human diet that contains cyclopropene fatty acids and such acids (as sterculic acid) when fed at 5% of dietary energy to rats caused death and at the 2% level caused disturbances of reproduction, and there has been concern about the effect in Humans (Gurr, 1989).

Although there has been no evidence that the consumption of cottonseed oil in manufactured products has any harmful nutritional effects, but the imbalance between the percentage of Omega-6 fatty and Omega-3 fatty acid content of the cottonseed oil is regarded as harmful, unless supplemented elsewhere in the diet (Mustapha et al., 2016). For this reason, cottonseed oil has huge capability for biodiesel production. If cottonseed oil can be converted into a more profitable commercial product, the abandoned cotton farming can be revived and therefore create more employment opportunities. Therefore, the development of cottonseed oil biodiesel would be in harmonious correlation with sustainable development, energy conservation and security.

There are numerous research works conducted regarding the impact of cottonseed oil methyl ester on the performance of diesel engines. Tejrao and Kiran (2015) tested the cottonseed oil methyl ester (Biodiesel) produced using NaOH as catalyst, in a compression ignition (C.I.) engine and the result showed that the brake thermal efficiency is same for ester(biodiesel) and diesel. Similarly, Vijayaraj and Sathiyagnanam (2014) carried out experimental investigation of methyl ester of cottonseed oil blend with diesel on C.I. engine and concluded that, the brake specific fuel consumption increases with increase in percentage of biodiesel in the blends due to lower heating value of biodiesel, and also, the brake thermal efficiency of B25 (i.e. 25 wt. % biodiesel in diesel-biodiesel blends) is closer to diesel at all loads. Bhoreja and Prayagi (2012) also conducted a performance analysis of cottonseed oil methyl ester for compression ignition engines and they observed that both the brake thermal efficiency and indicated thermal efficiency of the engine using cottonseed oil methyl ester is greater in comparison with Jatropha biodiesel and petroleum diesel.

From reported literature however, there were conflicting results about the impact of the cottonseed oil on the performance of diesel engines. For example, Tejrao and Kiran (2015) reported that brake thermal efficiency of the
cottonseed oil biodiesel is the same with diesel, while Bhojraj and prayagi (2012) observed that brake thermal efficiency of the cottonseed oil biodiesel is greater than that of petro-diesel. This may be due to some differences/variations in the properties of the biodiesel tested. For instance, if the cetane numbers of the fuels differ, the thermal efficiencies with the use of those fuels would also differ (Sabah & Miqdam, 2012). One of the suspected reasons for these variations in properties might be the type of catalyst used for the transesterification of the cottonseed oil, as observed. The suspicion was motivated by the results of the research conducted by Shankar et al. (2016) on the production of biodiesel from cottonseed oil using two different catalysts (homogeneous catalyst and heterogeneous catalyst). They found the viscosity of the biodiesel produced to be 2.975 mm²/s and 2.496 mm²/s; density of 0.898 g/cm³ and 0.963 g/cm³ using NaOH (as homogeneous catalyst) and multi walled carbon nanotubes (as heterogeneous catalyst) respectively. Although, the authors didn’t specify the reason for the difference in the properties but, one may assume that it was because of the use of different catalyst for the biodiesel production. Therefore, there is a need for further research to ascertain these claims. It is within this context, that this study was conducted to investigate the effect of the properties of three biodiesel samples produced from cottonseed oil (via transesterification process) using three different catalysts, (single catalyst per sample) on the performance of a diesel engine.

2 MATERIALS AND METHOD
2.1 BIODIESEL PRODUCTION

Raw cottonseed oil usually contains high free fatty acids (FFAs) value of about 5 wt. % (Lebnebiso et al., 2015). However, when a feedstock (oil or fats) contains a high percentage of free fatty acids (greater than 1wt. %), during transesterification, the alkali catalyst will react with the free fatty acids to form soap. Therefore, prior to the transesterification reaction, the acidic feedstock (containing high amount of FFAs) should be pre-treated (esterification or alcoholysis) to inhibit the saponification reaction (Gopal et al. 2015; Patni et al., 2013; Lebnebiso et al., 2015). Therefore, due to this factor, the biodiesel production was carried out in two stages.

The first stage utilized the Esterification process to reduce the FFA content of the raw cottonseed oil. The reaction was carried out using crude cottonseed oil with methanol (using 12:1 methanol to oil molar ratio) and concentrated sulphuric acid (H₂SO₄) as the catalyst (1 wt. % of oil) at 40°C for 2 hours. After the esterification, an average of 98% conversion of the raw cottonseed oil to ester (esterified oil) was achieved.

The second stage utilized transesterification process to obtain the final product (biodiesel). The reaction was carried out with methanol to oil molar ratio of 6:1, catalyst concentration of 1 wt. %, reaction temperature of 65°C and 1 hour reaction time. These reaction conditions were regarded as the best conditions for the production of biodiesel by transesterification using basic catalyst (Ude et al., 2014; Ibrahim et al., 2013). The transesterification process was carried out in three separate batches using three different catalysts. The catalysts used were sodium hydroxide (NaOH) as homogeneous catalyst, calcium oxide (CaO) as heterogeneous catalyst and Nano Calcium oxide (Nano CaO) as Nano-heterogeneous catalyst. After the transesterification reaction was completed, the biodiesel was separated from the glycerol and the biodiesel samples were denoted according to the type of the catalyst used for its transesterification, i.e. B-NaOH, B-CaO and B-Nano-CaO, for NaOH, CaO and Nano-CaO catalysts, respectively. B-NaOH being transesterified using a homogeneous catalyst (NaOH), was further purified by washing for several times with warm distilled water at 60°C to remove impurities and traces of catalyst and then it was heated in an oven at 100°C for 30 minutes to remove traces of unreacted alcohol and water (Lebnebiso et al., 2015, Gopal et al., 2015; Numan & Leyla, 2008).

2.2 TESTING THE BIODIESEL SAMPLES IN THE COMPRESSION IGNITION (DIESEL) ENGINE

A single cylinder Viking Super 165F diesel engine was used as the test engine. It is an air-cooled direct injection, four-stroke, horizontal type engine as shown in Figure 1.

![Test Engine Set up with the instrumentation unit](image)

The engine was mounted on a test bench and then connected to a hydraulic dynamometer and instrumentation unit (which has accessories for monitoring fuel consumption, torque and air flow) as shown in figure 1. Exhaust gas temperature was measured by K type thermocouple inserted into exhaust pipe and the engine speed was measured using a tachometer. Table 1 summarizes the test engine specifications.

| Table 1. Test Engine Specifications |
|------------------------------------|
| **Description** | **Specifications** |
| Engine model | 165F |
| Type | Horizontal Single Cylinder Four stroke, air cooled |
| Bore/Stroke | 65/70mm |
| Compression Ratio | 20.5:22 |
| Max. Torque | 10 Nm |
| Max. Brake Power | 2.43 kW |
| Rated Speed | 2600 rpm |
| Fuel injection pressure | 14 MPa |
| Injection opening angle | 20–24° before T.D.C. |

Fig. 1: Test Engine Set up with the instrumentation unit
The fuel sample was fed from a detachable fuel tank mounted on the instrumentation unit and was being gravity-fed to the engine, which was positioned below the level of the tank. The engine tests were conducted at constant throttle position (three-quarter opened). The torque on the engine was varied from 4Nm to 10Nm and the corresponding speed, fuel consumption, and exhaust temperature were recorded. The procedure was repeated with the throttle position kept constant while varying the load for diesel fuel and the biodiesel samples. All readings were taken after stable operating conditions were experimentally achieved. The parameters recorded at each operating condition include: engine speed (rpm); torque (Nm); exhaust temperature (°C); volume of fuel consumed (ml); and time(s) taken to consume the specific volume of fuel.

3 RESULTS AND DISCUSSION
3.1 CHARACTERIZATION OF THE BIODIESEL SAMPLES
The physico-chemical properties of the fuel samples are presented in table 2 below.

Table 2. Physico-Chemical Properties of the Biodiesel Samples Compared to Petro-Diesel and ASTM D6751 Biodiesel Standard

| Property                | B-NaOH | B-CaO | B-Nano-CaO | Petro-diesel | ASTM D6751 |
|-------------------------|--------|-------|------------|-------------|------------|
| Percentage yield (%)    | 94     | 96.5  | 99         | -           | -          |
| Density (g/ml)          | 0.8320 | 0.8655| 0.8670     | 0.8250      | 0.83-0.88  |
| Kin. Viscosity @ 40°C (cSt) | 3.00  | 3.65  | 3.65       | 2.25        | 1.9-6.0    |
| Pour point (°C)         | -6     | -8.5  | -8.6       | -20         | -          |
| Cloud point (°C)        | 3      | 10    | 10         | -           | -          |
| Flash point (°C)        | 155    | 175   | 178        | 70          | 130 minum  |
| Iodine Value (g/100g)   | 61.9272| 72.0792| 71.4440    | 38.0000     | -          |
| Saponification Value (mg/g) | 193.96 | 200.98| 202.38     | -           | -          |
| Peroxide Value (mEq/g)  | 0.25   | 0.27  | 0.27       | -           | -          |
| Cetane Number           | 60.5062| 57.2391| 57.1942    | 49.0000     | 47/minim  |
| Calorific value (kJ/kg) | 37412  | 37870 | 37907      | 42500       | -          |

The characterization results showed that highest percentage yield (99%) was obtained using Nano-CaO as catalyst followed by CaO (96.5%) and NaOH (94%) after transesterification reaction of the esterified cottonseed oil. B-CaO and B-Nano-CaO biodiesel samples possess similar properties because both were transesterified using heterogeneous catalyst (i.e. same category of catalyst) while the properties of B-NaOH (transesterified using homogeneous catalyst) slightly differs. This might be due to the purification stages undergone by the B-NaOH biodiesel after transesterification (washing to remove catalyst/impurities and drying to remove traces of moisture), which was not done in the case of B-CaO and B-Nano-CaO biodiesel samples. But nonetheless, all the biodiesel samples produced comply with most of the parameters of the ASTM D6751 biodiesel standards.

3.2 IMPACT OF THE BIODIESEL SAMPLES ON THE PERFORMANCE OF DIESEL ENGINE
The engine test of the biodiesel samples was conducted on a Viking super 165F diesel engine using 100% of the biodiesel samples (i.e. B100). 100% petro-diesel was also tested for comparison with the biodiesel samples. All tests were conducted at constant throttle position (three-quarter open), while the load (in form of torque) was varied. For every change in load, the corresponding speed (rpm), exhaust temperature (°C), and fuel consumption (ml/s) were recorded. The brake power, brake thermal efficiency, and specific fuel consumption were calculated analytically according to the load applied. The experimental data and analysis obtained were presented in Table 3 and Table 4.

Table 3. Experimental Results of the Effectiveness of the Fuel Samples on the Performance of the Diesel Engine

| Sample      | Torque (Nm) | Engine speed (rpm) | Exhaust temp. (°C) | Fuel consumption (ml/s) |
|-------------|-------------|--------------------|--------------------|-------------------------|
| B-Petro-diesel | 4           | 2030               | 132                | 0.118                   |
|             | 6           | 2000               | 166                | 0.139                   |
|             | 8           | 1980               | 189                | 0.157                   |
|             | 10          | 1940               | 233                | 0.189                   |
| B-NaOH      | 4           | 2050               | 142                | 0.120                   |
|             | 6           | 2020               | 167                | 0.142                   |
|             | 8           | 1920               | 182                | 0.156                   |
|             | 10          | 1850               | 214                | 0.186                   |
| B-CaO       | 4           | 1915               | 136                | 0.110                   |
|             | 6           | 1860               | 161                | 0.134                   |
|             | 8           | 1754               | 185                | 0.141                   |
|             | 10          | 1770               | 220                | 0.186                   |
| B-Nano-CaO  | 4           | 2040               | 140                | 0.117                   |
|             | 6           | 1990               | 170                | 0.143                   |
|             | 8           | 1960               | 200                | 0.156                   |
|             | 10          | 1850               | 216                | 0.185                   |

Table 4. Calculated Results of the Effectiveness of the Fuel Samples on the Performance of the Diesel Engine

| Sample      | Torque (Nm) | Brake power (kW) | Brake thermal efficiency (%) | Brake specific fuel consump (g/kW-s) |
|-------------|-------------|------------------|------------------------------|-------------------------------------|
| B-Petro-diesel | 4           | 0.8588           | 19.46                        | 0.1147                              |
|             | 6           | 1.2568           | 24.31                        | 0.0918                              |
|             | 8           | 1.6590           | 26.33                        | 0.0798                              |
|             | 10          | 2.0318           | 28.85                        | 0.0774                              |
| B-NaOH      | 4           | 0.8588           | 22.96                        | 0.1105                              |
|             | 6           | 1.2482           | 28.03                        | 0.0897                              |
|             | 8           | 1.4881           | 30.60                        | 0.0829                              |
|             | 10          | 1.8988           | 32.93                        | 0.0791                              |
| B-CaO       | 4           | 0.8424           | 24.40                        | 0.1087                              |
|             | 6           | 1.2273           | 29.09                        | 0.0912                              |
|             | 8           | 1.6496           | 33.37                        | 0.0795                              |
|             | 10          | 1.8800           | 32.76                        | 0.0819                              |
| B-Nano-CaO  | 4           | 0.8546           | 23.09                        | 0.1144                              |
|             | 6           | 1.2505           | 27.65                        | 0.0954                              |
|             | 8           | 1.6422           | 33.35                        | 0.0791                              |
|             | 10          | 1.8794           | 32.15                        | 0.0821                              |
Brake Power: Brake power is the output power of an engine measured by developing the power into the hydraulic dynamometer attached to the output shaft. The torque was applied and the value was displayed on the TechQuipment TD114 instrumentation unit and tachometer was used to measures the speed of the output shaft. The brake power was calculated with the formula:

\[
\text{Brake power (B. P.)} = \frac{2\pi NT}{60}
\]  

(1)

Where \(N\) = shaft speed in revolution per minute (rpm)

\(T\) = torque in Nm

The variations of brake power with the torque of the petro-diesel and the biodiesel samples tested are presented in the Figure 2.

The brake power developed by the engine fueled with diesel and the biodiesel samples followed an increasing trend with respect to the torque. At higher torque (8-10Nm), the brake power developed by the engine run on biodiesel samples was observed to be lower than that obtained using petro-diesel. This was as a result of the relatively lower calorific values of the biodiesel samples as compared to the petro-diesel.

A comparison of the brake power developed by the engine operating on the three biodiesel samples indicates that B-NaOH has relatively higher brake power (6.5% lower than that of petro-diesel) at almost all torques compared to B-CaO (7.5% lower than that of petro-diesel) and B-Nano-CaO (7.6% lower than that of petro-diesel). This was because of its relatively higher cetane number. Cetane number indicates the measure of the ignition quality of diesel fuel, its increments reduce ignition delay period and thereby, making the stroke faster which consequently increases the engine speed. Thus, increase in cetane number of a fuel increases the brake power (Sabah & Miqdam, 2012).

Brake Thermal Efficiency: It is the ratio of the brake power produced to the energy in the fuel burned to produce the engine brake power. It indicates how much of the fuel energy is converted into useful brake power. The brake thermal efficiency was calculated using the following expression:

\[
\eta_{\text{th}} = \frac{(\text{Brake power})}{(m_f \times Q_f)}
\]  

(2)

Where \(m_f\) = mass flow rate of fuel

\[=\text{Density} \times \text{Volume}/\text{Time}\]

\(Q_f\) = Calorific value of fuel

The brake thermal efficiency of the tested samples increases with an increase in torque, except for the B-CaO and B-Nano-CaO which decreased after the application of 8Nm torque. The brake thermal efficiencies of the biodiesel samples were higher than that for petro-diesel at all torques. This might be as a result of their higher cetane number as compared to that of petro-diesel. This showed that the increase in the cetane number of the biodiesel samples above petro-diesel by 23%, 17%, and 16.7% for B-NaOH, B-CaO, and B-Nano-CaO biodiesel samples respectively, lead to the increase in brake thermal efficiencies of the biodiesel samples above petro-diesel by 14.14%, 13.55%, and 11.44% for B-NaOH, B-CaO, and B-Nano-CaO biodiesel samples respectively. Since brake thermal efficiency is an indication of the useful thermal power produced from fuel burning, therefore, burning improvements (such as increase in cetane rating) could cause higher brake thermal efficiency (Sabah & Miqdam, 2011; Bhoraj & Prayagi, 2012).

Brake Specific Fuel Consumption (BSFC): It is defined as the fuel flow rate per unit brake power output. It is the measure of how efficiently the fuel supplied to the engine is used to produce power and is expressed as follows:

\[
\text{BSFC} = \frac{m_f}{\text{Brake power}}
\]  

(4)

Where \(m_f\) = mass flow rate of fuel

The variations of specific fuel consumption with the torque for the petro-diesel and the biodiesel samples tested are presented in the figure 4 below:
The specific fuel consumption decreases with increase in torque for all the biodiesel samples as shown in figure 3.3. This indicates that, the engine consumes lower amount of fuel to overcome relatively higher amount of load. The specific fuel consumption of the engine running on the biodiesel samples was observed to be higher than that for petro-diesel by 2.2%, 5.8%, and 6.1% for B-NaOH, B-CaO, and B-Nano-CaO biodiesel samples respectively, as the torque increases. This may be due to their relatively lower calorific values compared to petro-diesel.

B-NaOH has the lowest BSFC almost at all load amongst the biodiesel samples and this might be due to its lower viscosity and higher cetane number which gave it the abilities of proper atomization (at injection) and efficient combustion. This is supported by the suggestion that, increase in cetane number of a fuel improves combustion and raises the combustion chamber temperatures. The rise in combustion chamber temperature will facilitate increase in thermal efficiency and thereby, reducing the fuel consumption (Sabah & Miqdam, 2012). On the other hand, low cetane number increases fuel ignition delay period which result in poor combustion and therefore, more fuel is burnt at higher loads to meet the power requirement (Obodeh & Isaac, 2011). Thus, it could be concluded that the possession of higher cetane number reduces the fuel consumption of fuels with low calorific values.

4 CONCLUSION
The effect of properties of cottonseed oil biodiesel on the performance of a diesel engine was investigated in this study. The characterization results showed that B-CaO and B-Nano-CaO biodiesel samples possess similar properties because both were transesterified using same category of catalyst (i.e. heterogeneous catalyst) while the properties of B-NaOH (transesterified using homogeneous catalyst) slightly differs. It was suggested that the difference was due to the purification stages undergone by the B-NaOH biodiesel after transesterification which was not done in the case of B-CaO and B-Nano-CaO biodiesel samples. But all the biodiesel samples produced comply with most of the parameters of the ASTM D6751 biodiesel standards.

Based on the test of the biodiesel samples conducted on the diesel engine, the break thermal efficiency of the engine with the use of the biodiesel samples was greater in comparison with petro-diesel and B-NaOH biodiesel gave the highest brake thermal efficiency among the biodiesel samples tested. On the other hand, the brake specific fuel consumption (BSFC) of the engine running on the biodiesel samples is higher than that for petro-diesel as the torque increases and this may be due to their lower calorific values, and B-NaOH has the lowest BSFC almost at all load amongst the biodiesel samples tested. From the tests result however, it could be suggested that, variation in the properties of a fuel has significant effect on the performance of a diesel engine.

REFERENCES
Bhojraj, N. K. and Prayagi, S.V. (2012). Performance Analysis of Cottonseed Oil Methyl Ester for Compression Ignition Engines. International Journal of Emerging Technology and Advanced Engineering, 2(8), 117-120.

Gopal, B. V., Sridevi, V., Sarma, A. J., and Rao, P. V. (2015). Processing and Characterization of Cotton Seed Methyl Ester. Austin Chemical Engineering, 2015; 2(2): 1020.

Curr M. I. (1989). The nutritional significance of lipids. In Developments in Dairy Chemistry-2: Lipids, Ed. P.F. Fox, Applied Science, London, 1989, pp. 365-417.

Ibrahim, H., Ahmed, A. S., Bugaje, I. M., Mohammed, D., Ugwumma, C. D. (2013). Synthesis of Bulk Calcium Oxide (CaO) Catalyst and its Efficacy for Biodiesel Production. Journal of Energy Technologies and Policy, 3(12), 14-16.

Jordan H., James J., Kailyn S., and Jason D. (2017). Energy Education – Diesel [Online]. Available: https://energyeducation.ca/encyclopedia/Diesel. Retrieved: November 21, 2018.

Lebnebiso, J. S., Aberuagba, F., Ndagana, S. F. and Okoye, S. I. (2015). Transesterification Of Esteriﬁed Crude Cotton (Gossypium Hirsutum) Seed Oil. International Journal of Scientiﬁc Research and Innovative Technology, 2(7), 5-12.

Mehmood, T. Eikhoosro K., Rajev K., and Ilona S. H. (2015): Renewable Energy and alternative fuel technologies. BioMed Research International, Vol. 2015, Article ID 245935, 2 pages, 2015. https://doi.org/10.1155/2015/245935.

Mustapha, M., Haruna, M. K., Awwal, S. and Ibrahim A. (2016). Optimization of Biodiesel Production from Crude Cotton Seed Oil Using Central Composite Design. American Journal of Chemical and Biochemical Engineering, 1(1), 8-14.

Numan, H. and Leyla, B. (2008, October). Optimization of Biodiesel Production from Cottonseed Oil by Transesterification Using NaOH and Methanol. 10th International Congress on Mechanization and Energy in Agriculture, Held at Antalya-TURKIYE, Turkey.

Obodeh, O. and Isaac, F. O. (2011): Investigation of Performance Characteristics of Diesel Engine Fuelled with Diesel-Kerosene Blends. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), 2(2), 318-322.

Patni, N., Bhonia, C., Dasgupta, P. and Tripathi, N. (2013). Use of Sunflower and Cottonseed Oil to Prepare Biodiesel by Catalyst Assisted Transesterification. Research Journal of Chemical Sciences, 3(3), 42-47.

Refaat, A. A. (2011). Biodiesel production using solid metal oxide catalysts. International Journal of Environmental Science and Technology, 8 (1), 203-221.

Sabah, T. A. and Miqdam, T. C. (2012). Effect of Fuel Cetane Number on Multi-Cylinders Direct Injection Diesel Engine Performance and Exhaust Emissions. Al-Khairawi Engineering Journal, 8(1), 65-75

Shankar, A. A., Pentapati, P. R. and Prasad R. K. (2016). Biodiesel Synthesis from Cottonseed Oil using Homogeneous Alkali Catalyst and using Heterogeneous Multi Walled Carbon Nanotubes: Characterization and Blending Studies. Egyptian Journal of Petroleum, Vol. 26(2017), 125–133.

Tejrao, G. and Kiran, T. (2015): Cottonseed Oil as an Alternative Fuel for C.I. Engine. International Journal of Modern Trends in Engineering and Research (IJMTER), 2(02), 2349-9745.

Ude, C. N., Ahmed, E. J., Onyiah, M. I., Anisiij, O. E. and Ude, E. N. (2014). Heterogeneous Catalyzed Transesterification of Refined Cottonseed Oil to Biodiesel. Pacific Journal of Science and Technology, 15(2), 71-77.

Vijayaraj, K. and Sathivagnanam, A.P. (2014): Experimental Investigation of Methyl Ester of Cotton Seed Oil Blend with Diesel on CI Engine. American Journal of Applied Sciences, 11(10), 1819-1829.