INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 2, Issue 2, 2011 pp.321-330
Journal homepage: www.IJEE.IEEFoundation.org

Effect of diesel addition on the performance of cottonseed oil fuelled DI diesel engine

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Abstract
In this investigation the viscosity of cottonseed oil, which has been considered as an alternative fuel for the compression Ignition (C.I) engine was decreased by blending with diesel. The blends of varying proportions of cottonseed oil and diesel were prepared, analyzed and compared with the performance of diesel fuel and studied using a single cylinder C.I. engine. Significant improvement in engine performance was observed compared to neat cottonseed oil as a fuel. The brake thermal efficiency, specific fuel consumption, volumetric efficiency, peak cylinder pressure, smoke, CO, HC, NO and the exhaust gas temperatures were analyzed. The tests showed increase in the brake thermal efficiencies of the engine as the amount of diesel in the blend increased. The volumetric efficiency of the engine also increased when compared with that of neat cottonseed oil and the exhaust gas temperature with the blends decreased. The smoke, CO and HC emissions of the engine ware also less with the blends. From the engine test results it has been established that 20–40% of cottonseed oil can be substituted for diesel without any engine modification as a fuel.

Keywords: Cottonseed oil, Blending, Combustion, Diesel engine, Blending, Emission, Performance.

1. Introduction

The fast depletion of world petroleum reserves and the importance of environmental pollution of increasing exhaust emissions, there is an urgent need for identifying a suitable alternative fuel for use in diesel engines. In view of this, vegetable oil is considered a promising candidate as an alternative because it has several advantages like; it is renewable, environment friendly and produced easily in rural areas. Therefore, during recent years a systematic approach has been made by several researchers to use vegetable oils as a fuel in IC engines. Even though the use of non-edible vegetable oils compared to edible oils is very significant, edible oils like rice bran oil and cottonseed oil are having tremendous potential as alternate fuels.

From the research and studies carried out in the past, it is evident that there are various problems associated with the use of vegetable oils as fuel in compression ignition engines, predominantly caused by their high viscosity and poor volatility [1]. The high viscosity is due to the large molecular mass and complex chemical structure of vegetable oils that in turn leads to problems related to pumping, combustion and atomization in the injector system of a diesel engine. Due to the high viscosity, the long term operation of the engine with vegetable oils normally introduce the development of gumming, the formation of injector deposits, ring sticking and problems related to the lubricating oils [2]. Therefore, the reduction of viscosity of vegetable oils is of prime importance to make it a suitable alternative fuel for diesel engines. The problem of high viscosity of vegetable oils can be reduced in several ways, such as transesterification [3, 4], micro emulsification [5], preheating the oils [6] and blending with other fuels such as diesel [7], oxygenated organic compounds [8], and methanol [9]. Emission levels of the blends of diesel and vegetable oils were found to be reduced [10].

In the present investigation cottonseed oil, which is considered a potential alternative fuel for C.I. engine, has been chosen to find out its suitability for use as fuel oil. The properties of cotton seed oil compares well against other vegetable oils and more importantly to diesel itself in terms of its fuel rating. However, the greatest difference between cottonseed oil and diesel oil is its viscosity. The high viscosity of cottonseed oil may contribute to the formation of carbon deposits, incomplete combustion and increased emission from the engine.

Therefore, in this study a simple method of increasing the efficiency and reducing the exhaust gas emissions of the diesel engine without any compromise on the power output of the engine, has been adopted. Vegetable oils can be easily mixed with diesel in any proportion and can be used to partially substitute diesel. Blending vegetable oils with diesel results in the reduction of viscosity of the mixture. Diesel and cottonseed oil blends of 20%, 40%, 60% and 80% by volume were prepared and tried in the diesel engine at the rated speed of 1500 rpm. The properties of test fuels are given in Table 1.

The main objectives of the present study are:

- To decrease the viscosity of the oil by blending with diesel
- To evaluate the engine performance using the prepared blends as fuel
- To study the effect of using fuel blends on the emission levels

Table 1. Properties of test fuels

Properties	Diesel	Cottonseed oil
Density, kg/m^3 @ 30°C	835.9	909
Kinematic Viscosity, cSt @ 40°C	3.9	32.7
Cetane Number	45	42
Flash Point, °C	56	234
Calorific Value, kJ/kg	42500	40358

2. Experimental setup

The experimental setup used for this work consists of a single cylinder, four stroke, Kirloskar TV1, direct injection diesel engine. It has a displacement volume of 661 cc, and a rated power of 5.2 kW @ 1500 RPM. It is attached to a Saj Fraud 20 kW Eddy Current dynamometer. The engine specifications are given in Table 2. The experimental setup is shown in Figure 1. The engine was not modified in any way for use with the blended fuels. A Dynalog data acquisition unit and a personal computer were used to collect for data every 2° of crankshaft revolution for each of the tests. Torque, power, fuel consumption and temperatures at various locations of the engine were monitored throughout the testing and saved into a data file, which was converted into the graphical form for better presentation.

Load was changed in five levels; 20%, 40%, 60%, 80% and 100%. The engine was operated at the rated speed for all the tests. Concentration of CO and HC were measured with a Crypton exhaust gas analyzer. NO was measured with a Kane-May KM82 exhaust gas analyzer. Smoke density was also measured for every blend at each load by means of a Diesel smoke meter. Kinematic viscosities of the fuel were measured with a Saybolt Viscometer at 40ºC.

3. Results and discussion

Kinematic viscosity of the cottonseed oil was nearly 15 times as high as that of diesel. However, a significant reduction in the viscosity of the blend was noticed as the quantity of diesel in the blend was increased. The variations of viscosity for different blend proportions are given in Figure 2.

Table 2. Specification of engine

Make and model	Kirloskar, TV_1
No. of cylinder	1
Cycle	4 stroke
Bore × Stroke	87.5 mm × 110 mm
Displacement volume	661 cm^3
Compression ratio	17.5: 1
Combustion chamber	Hemispherical
Rated power	5.2 kW @ 1500 rpm
Injection Timing	27º BTDC

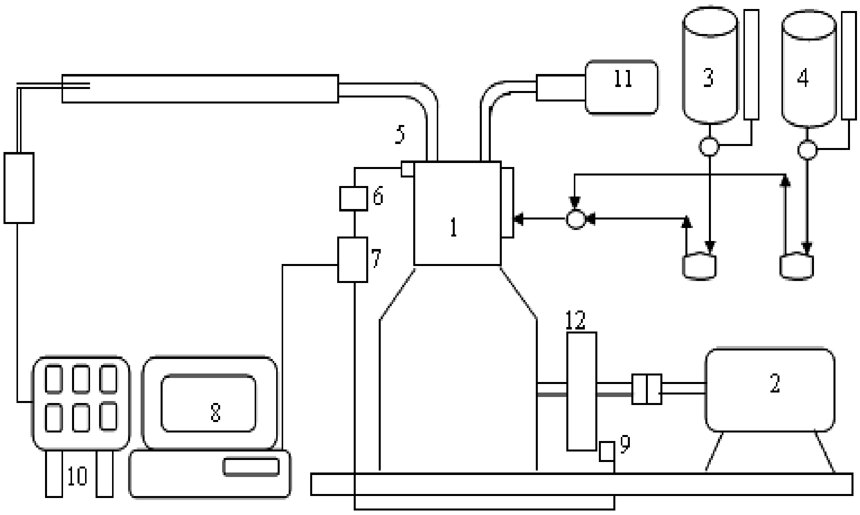

Figure 1. Schematic diagram of experimental setup. 1. Engine, 2. Eddy current dynamometer, 3. Diesel fuel tank, 4. CSO/Diesel fuel tank, 5. Pressure transducer, 6. Charge amplifier, 7. Analog to digital convertor, 8. Computer, 9. TDC pickup, 10. Exhaust gas analyzer, 11. Air surge tank, 12. Flywheel

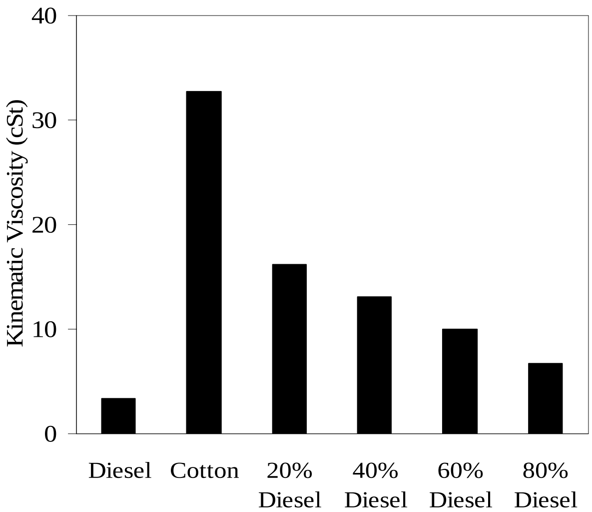

Figure 2. Kinematic viscosity of the blends at 40ºC

3.1 Brake thermal efficiency

The brake thermal efficiency plots in Figure 3 show an increase of brake thermal efficiency with increase in the engine load as the amount of diesel in the blend increases. Even a small quantity of diesel in the blend improves the performance of the engine. With 20% diesel in the blend, the brake thermal efficiency increases from 28% to 29.21%. The blend containing 80% diesel shows the highest brake thermal efficiency, which is very close to diesel. The value is 31.6% as against 32.3% for diesel at 100% load. This is due to the reduction in viscosity, density and carbon residue in the blend and increase in the heating value as the proportion of diesel in the blend increases.

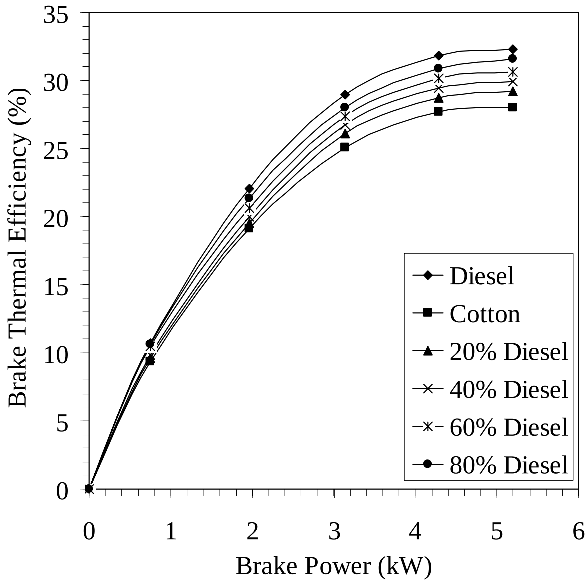

Figure 3. Variation of brake thermal efficiency with brake power

3.2 Volumetric efficiency

The variation of volumetric efficiency is shown in Figure 4. There is an improvement in volumetric efficiency with increase in the proportion of diesel in the blend. The volumetric efficiency of diesel is the highest followed by 80%, 60%, 40%, 20% diesel blends. The low volumetric efficiency of neat CSO is due to its high exhaust gas temperature. High exhaust gas temperature retained in the cylinder will heat the incoming fresh air and this will result with reduction of volumetric efficiency.

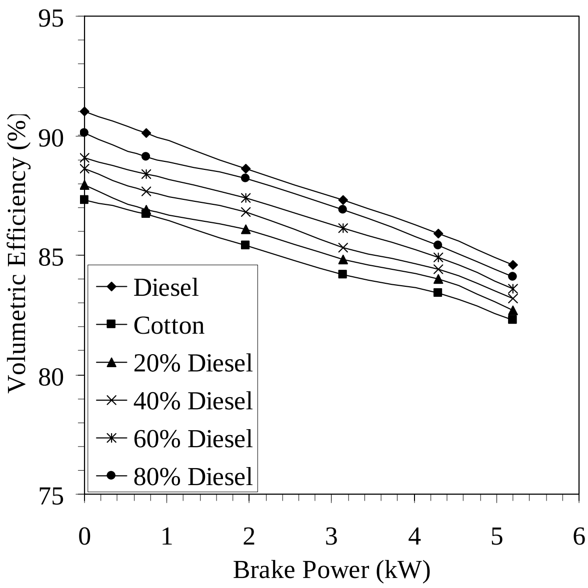

Figure 4. Variation of brake volumetric efficiency with brake power

3.3 Exhaust gas temperature

The variation of exhaust gas temperature of diesel, CSO and the blends are shown in Figure 5. The exhaust gas temperature was the highest for CSO and the least for diesel for all loads. This is due to the slow combustion of CSO due to the high viscosity and poor volatility. The maximum temperature of the

EGT gradually decreases due the improved combustion as a result of better mixture formation with the reduced viscosity.

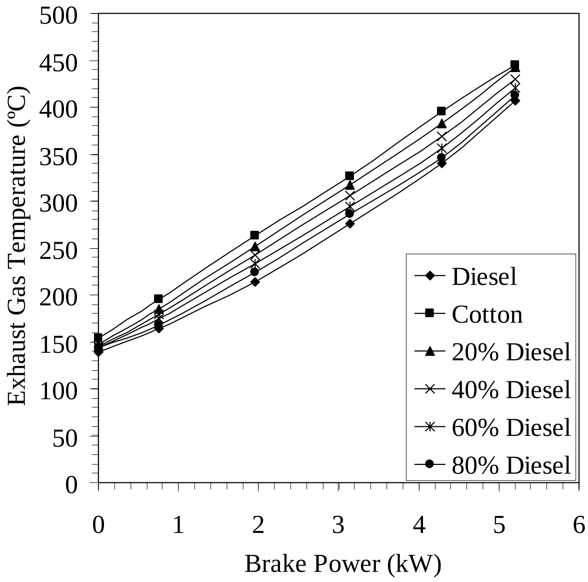

Figure 5. Variation of exhaust gas temperature with brake power

3.4 Smoke emission

Figure 6 shows the smoke emission. At full load, the smoke density is 3.9 BSU with CSO and 3.4 BSU with diesel. Due to higher viscosity, atomization becomes poor and this leads to larger droplet sizes consequently sluggish combustion which results in higher smoke emission for CSO. As the blend proportion increases, there is a drop in the smoke emission. The maximum smoke emission for 80 % diesel blend is 3.4 BSU as same as for diesel. This is because of the better mixture formation with the blend.

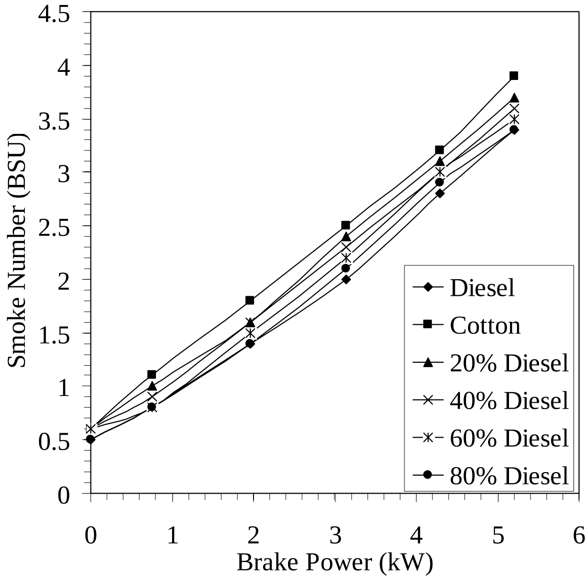

Figure 6. Variation of smoke emission with brake power

3.5 HC emission

Figure 7 shows the variation of HC emission. CSO results in higher HC emission compared to diesel. At full load the HC level for CSO is 75 ppm and for diesel it is 50 ppm. High viscosity leads to bigger fuel droplets and hence a non uniform distribution with air. Non uniform distribution will lead to too rich pockets that can result in HC. This higher viscosity of CSO can be reduced by blending with diesel. With

80 % blend a marginal reduction of HC emission (55 ppm) is noticed. The reduction in HC reduction is due to the improved mixture formation and complete combustion because of the changed physical properties compared to neat CSO.

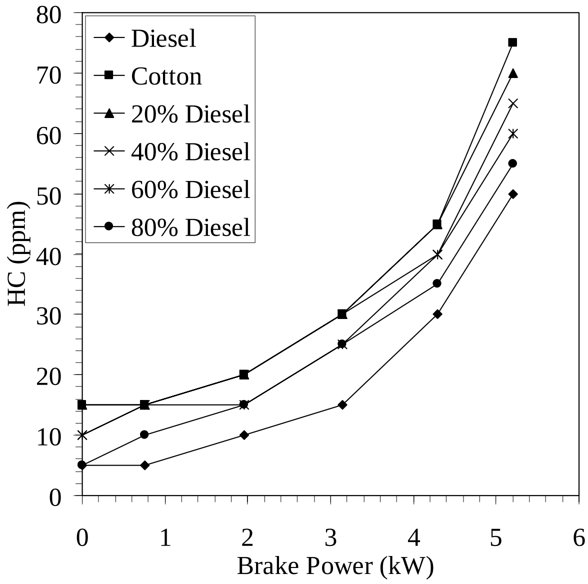

Figure 7. Variation of HC emission with brake power

3.6 CO emission

The variation in CO emission is given in Figure 8. The CSO gives slightly higher CO emission compared to diesel. The percentage of CO emission with CSO and diesel is 0.28 and 0.19 respectively. This may be due to poor spray characteristics and hence improper mixing, resulting in poor combustion. It will reduce with the blends as compared to neat CSO. These trends indicate that the combustion efficiency improves with the blend of cottonseed oil with diesel. The combustion rate and hence the reduction in carbon monoxide emissions with the addition of diesel to cottonseed oil improves as compared to neat CSO. Since the increase in the quantity of diesel in the blend improves the performance from the emission point of view, the blend ratio is decided based on the amount of diesel to be replaced or the level of emission that can be tolerated.

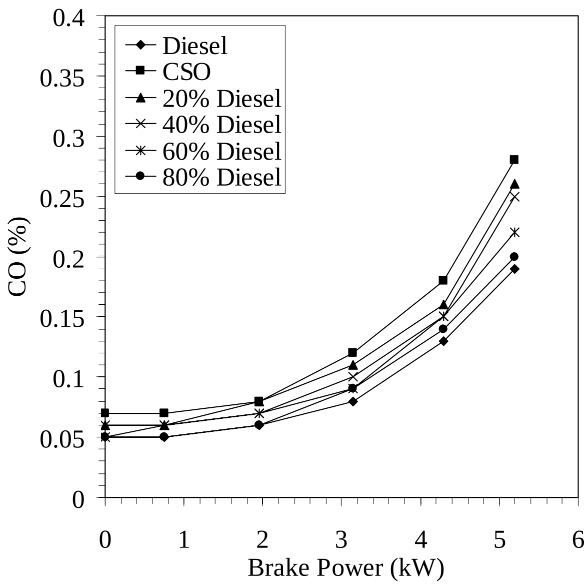

Figure 8. Variation of CO emission with brake power

3.7 NO emission

The variation in NO emissions with brake power for different blends with diesel is presented in Figure 9. NO emission for the neat CSO operation is 703 ppm and 756 ppm with diesel at full load. This reduction in NO with CSO operation is due to the less intensity of premixed combustion compared with diesel. NO concentration decreases as the amount of CSO in the blend goes up. The NO emission is 736 ppm at optimized CSO-diesel blend i.e. at 80 % diesel and 20 % CSO. The increase in NO is due to good mixing rate of fuel and air which leads to an increase in the premixed combustion.

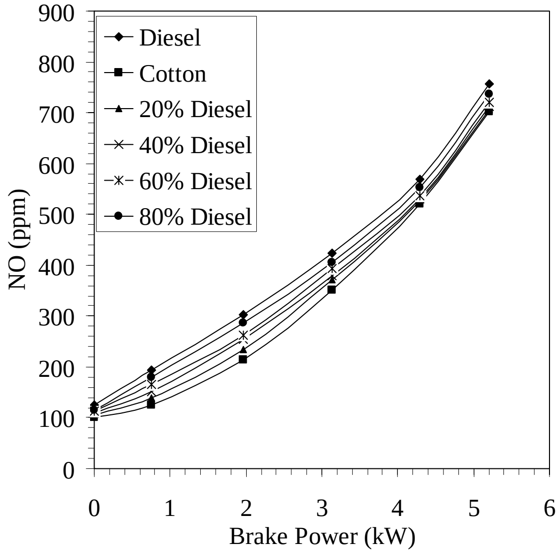

Figure 9. Variation of NO emission with brake power

3.7 Cylinder peak pressure and maximum rate of pressure rise

The variation of peak pressure and max rate of pressure rise are shown in Figure 10 and Figure 11. The values with neat diesel is the highest followed by the blends. The peak pressure with diesel is 73.21 bar followed by the 80% diesel blend whose value is 73 bar at full load. However as the quantity of diesel in the blend decreases the value falls. The trend of maximum rate of pressure rise is also the same. Peak pressure in a compression ignition engine depends on the combustion rate in the initial stages. As the diesel quantity in the blend is increased, the amount of fuel taking part in the uncontrolled combustion stage of the mixture has reduced, which has resulted in a better pressure rise. The higher viscosity and poor volatility of cottonseed oil, which lead to the poor atomization and mixture preparation with air during the ignition delay period has been improved by the addition of diesel.

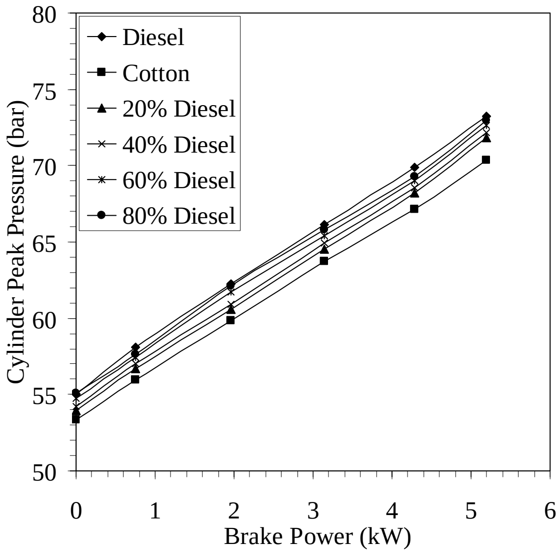

Figure 10. Variation of cylinder peak pressure with brake power

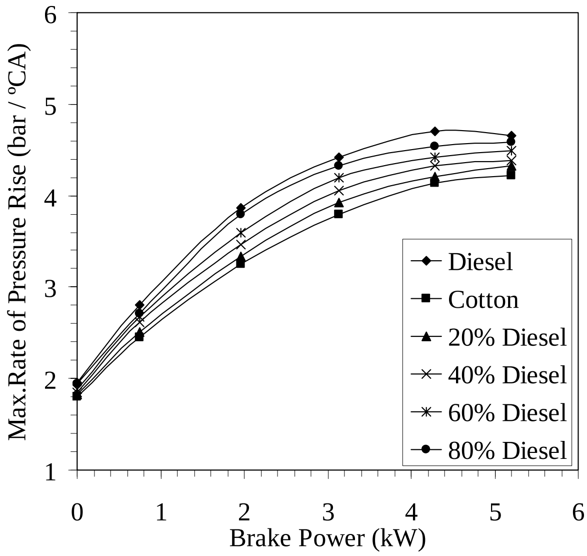

Figure 11. Variation of maximum rate of pressure rise with brake power

3.8 Heat release rate

The variation of heat release rate with crank angle at full load is shown in Figure 12. It can be observed that the heat release rate is high for diesel, is a consequence of premixed combustion phase. The premixed combustion phase is significantly lower for CSO compared to diesel. This is mainly due to high viscosity and low volatility of CSO leading to a reduction in fuel air mixing rates. The diffusion burning, indicated by the second peak is also higher with CSO due to the late burning of CSO. It also observed that higher premixed mixed combustion for diesel addition with CSO. This is due to more quantity of fuel being prepared during ignition delay period leads to bulk burning of fuel in the initial stage of combustion (premixed combustion).

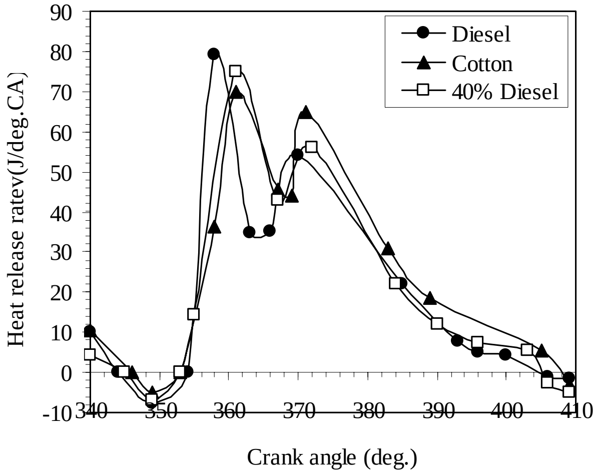

Figure 12. Variation of heat release rate with crank angle at full load

4. Conclusion

A single cylinder, compression ignition engine was operated successfully using cottonseed oil and diesel blends as fuel. The following conclusions are made based on the experimental results:

- In the case of cottonseed oil, the brake thermal efficiency, which was less, compared to diesel, increases appreciably with the addition of diesel. However, the increase depends on the quantity of diesel in the blend.
- At full load, smoke emission for cottonseed oil is quite high. As the quantity of diesel in the blend increases, the smoke level reduces.

- Hydrocarbon and carbon monoxide emissions are higher for cottonseed oil as compared to diesel. Blending with diesel reduces them further.
- Nitrous Oxide emissions of cottonseed oil and its blends are lower than diesel for all the loads.
- Peak pressure and maximum rate of pressure rise of cottonseed oil are comparable with diesel. However, a slight increase in these values was noticed with the addition of diesel.

Overall, it is concluded that 20-40% of cottonseed oil can be added to diesel and it can be used as a substitute fuel for diesel engines with out any engine modification. Further investigations are necessary especially related to long-term usage of vegetable oil diesel blends regarding deposit formation and lubricating oil stability.

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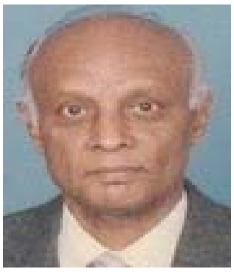

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