Comparative Study of Optimal Performance Parameters of VCR Engine at Different Compression Ratio Fueled with Different Blends of Cottonseed Biodiesel

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Abstract: The resource depletion has always been a concern regarding petroleum. Due to the increase in the price of petroleum, environmental concern and availability of fuels are greatly affecting the trends of fuels for transportation vehicles. To fulfill the rising energy demand renewable fuel like biodiesel is in forefront of other technologies. Biodiesel oil one of the options as alternative transport fuel. Cottonseed oil is non-edible vegetable oil, high viscosity, low volatility and widely available in India. In the present study, experimental investigations were carried out on a variable compression ratio diesel engine with cottonseed biodiesel -diesel blends (10–25% by volume) as fuel to determine the optimum blending ratio for the engine performance and comparative study done for optimal performance parameters of VCR engine at different compression ratio. It has been observed that B20 blend (20% cottonseed +80% diesel fuel) gives highest brake thermal efficiency & lowest brake specific fuel consumption as compared to all other blending combinations at different compression ratios.

Keywords: Biodiesel, Transesterification, cottonseed methyl ester, Brake thermal efficiency, Brake specific fuel consumption, Brake power, Compression ratio

1. INTRODUCTION

Presently the uses of petroleum based energy sources are very high as compared to non-conventional energy sources in spite of creating very high pollution. The present generation is heavily biased towards the conventional energy sources such as petroleum products, coal, atomic energy etc., which are finite in nature besides causing environmental pollution. The fast depleting petroleum reserves have already waved a warning signal all around the globe to look for alternate means to cater to the ever increasing needs of energy [1]. Our society relies heavily on internal combustion (IC) engines for different purposes, viz. transportation, agriculture and power generation. Therefore, research in both gasoline and diesel engines is required for improvement in fuel efficiency and emission reduction. Even a small improvement in fuel efficiency can have a major impact on economy and pollution [2].

Biodiesel oil one of the option as alternative transport fuel. Diesel fuel can be replaced by biodiesel made from vegetable oils. There are different types of vegetable oil available such as peanut, sunflower, rape, soybean, coconut, cottonseed, linseed, castor and mustard, has been tested worldwide [3].In modern economy the use of renewable and efficient biofuels is increasing due to cost competitiveness also. It has almost no Sulphur, no aromatics and more oxygen content which helps it to burn fully. It has higher cetane number which improves combustion. Since straight vegetable oils cannot be used directly without bringing its properties closer to petroleum fuel as diesel. Mainly viscosity reduction is sufficient to improve its flow and atomization properties. Four important techniques are available to reduce viscosity of these oils such as heating, transesterification, emulsification and blending [3] [4]. Transesterification (conversion of vegetable oil into biodiesel) is the best technique to bring the properties of vegetable oil closer to mineral diesel [5].

The main objective of the present research was to explore the possibility of running an IC engine on cottonseed oil in direct injection variable compression ratio (VCR) engine without any substantial modifications in the engine design. Characteristics of performance like brake torque, brake specific fuel consumption, thermal efficiency, exhaust gas temperature of biodiesel blended fuelled C.I. engine were calculated and compared with the values corresponding to diesel when the engine was running on different load conditions. A VCR engine was used to compare the performance of dual-fuel (cottonseed oil biodiesel + diesel) mode with that of neat diesel mode.

From the literature review, it is found that there is a substantial scope for the experimental investigation with cottonseed biodiesel at different compression ratio to quantify the optimum blend at different compression ratio. It is proposed to take up the research on the optimization of a single cylinder, 4-stroke VCR engine performance using different blends of cottonseed methyl ester with diesel at five different compression ratios (i.e. 14,15,16,17 and 18)

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Table 1 : Literature Review

Author	Engine Setup/ Parameters	Fuel used	Observation and results
Kumar et al. 2009 [3]	Single cylinder 4-stroke water cooled, research diesel engine	Cottonseed oil methyl ester (CSOME)	• Thermal efficiency of biodiesel slightly lower than Diesel. • BSFC increases with the biodiesel mixtures. • Decrease in PM, smoke and CO emission by 24%, 14% and 24% respectively. • Increase in the NOx 10%.
Nabi at el. 2009 [5]	Single cylinder 4-stroke, C.I engine	Cottonseed Biodiesel blended with diesel	• C10 blend reduces particulate matter by 24% and smoke emission by 14%. • C30 reduces CO emission by 24% but increase in NOx by 10%. • BTE of biodiesel mixtures was slightly lower than that diesel
Bhardwaj et al. 2014 [6]	Single cylinder, direct-injection diesel engine	Biodiesel from Used Cottonseed Oil	• Waste cottonseed oil biodiesel has more viscosity and less calorific value(4.76%less) • B10 showing better results in performance characteristics than B15 and B20
Kumar et al. 2012 [7]	Single cylinder 4-stroke, constant speed, CI engine	Cottonseed oil methyl ester (CSOME) and Neem methyl ester (NOME)	• Smoke and emissions for the blends of CSOME and NOME are less as compared to diesel. • CSOME – C20 is the optimum blend for performance and emissions.
Naidu et al. 2014 [8]	Single cylinder 4-stroke, C.I engine	Cottonseed Biodiesel blended with diesel	• The BTE of B20 is nearer to the diesel. • Cottonseed bio diesel– B20 is the optimum blend for better performance and emissions.
S. Kirankumar 2013 [9]	Single cylinder 4-stroke water cooled diesel engine	Cottonseed oil-diesel blends	• C30 has given the better performance (i.e. BTE, SFC) & emission parameters.
Vijayaraj, K. et al. 2014 [10]	Single cylinder 4-stroke, C.I engine	Cottonseed Biodiesel blended with diesel	• The BTE of B25 is very near to diesel at all loads. • BSFC increases with increase of biodiesel in the blends • Emission of CO, HC and smoke decreased, NO_x increased at full load.
R. Senthil Kumar et al. 2013 [11]	Air cooled, horizontal single cylinder with variable speed Greaves engine	Cottonseed Biodiesel blended with diesel	• The BTE of B20 is nearer to the diesel. • Cottonseed bio diesel– B20 is the optimal blend for improved performance and emissions. • B15 and B20 has a moderate emission
Ranganathan et al. 2012 [12]	Single cylinder 4-stroke, C.I engine	Cottonseed oil methyl ester (COME)	• BSFC for COME 90 is 7.8% higher, for Break specific energy consumption required for COME 0 is 4.4% high and for preheated COME 90 is 2.8% lower. • BTE for COME 90 increases by 2%.
Rakopoulos 2011 [13]	Six-cylinder, turbocharged heavy- duty, direct injection (DI),'Mercedes-Benz' diesel engine	Cottonseed oil methyl ester and Sunflower methyl ester	• Fuel injection pressure diagrams are almost unaffected. • The ignition delay is essentially the same. • Maximum cylinder pressures are slightly reduced. • Gross heat release rates delayed. • Cylinder temperatures are reduced.

Author	Engine Setup/ Parameters	Fuel used	Observation and results
Saleh 2010 [14]	Shock tube test rig.	Cottonseed oil Methyl Ester (CME) & Cottonseed oil Ethyl Ester (CEE)	• Ignition delay time is highest for CSO then CEE, CME and diesel. • Decrease in ignition delay time with increase of diesel. • For a characteristic value 0.7 the ignition delay for CEE, CME is less than 2ms except for CSO. • If initial temperature and pressure is increased
Shelke et al. 2016 [15]	Single cylinder 4-stroke diesel engines	Cottonseed oil methyl ester	• Ignition delay reduced from 11 ºCA to 6.5 ºCA for B20 as compared to diesel. • Combustion advanced from 349 ºCA to 344.5 ºCA for B20 as compared to diesel. • Peak in-cylinder pressure raised from 52.28 to 55.61 for B20. • The rate of pressure rise is decreased with all blends
Raj et al. 2017 [16]	Single cylinder 4-stroke diesel engines	Blends of cottonseed oil and isobutanol	• Reduction in the BSFC by 10% to lowest value for diesel. • Exhaust gas temperatures for blends are lower than diesel. • Increasing the amount of the cottonseed oil reduces the emission parameters • Isobutanol can be used as fuel additive & B20+ 10% Isobutanol blend is the most suitable blend
Capareda et al. 2008 [17]	3-Cylinder, Yanmar Engine	cottonseed oil biodiesel in fuel	• The difference between peak power output produced by blends less than B40 is insignificant as compared to diesel. • The peak brake power produced at B100 was 5% lower than for diesel fuel.

Figure 1 : Cottonseed oil with methanol & KOH

Figure 3 : Stirring on controlled temperature

Figure 2 : Mixing of oil mixture on magnetic stirrer with heating plate.

Figure 4 : Glycerin deposited in the bottom

2.1 Properties of test fuel

The key physical and chemical properties of Diesel and cottonseed biodiesel (B100) are shown in Table 2. These properties were compared on the basis of ASTM standards.

2. EXPERIMENTAL SETUP

A vertical single cylinder, DI, four-stroke, water-cooled, VCR (variable compression ratio), multi-fuel CI engine has been used for experiments. The detailed technical specifications of the engine are given in Table 3. The compression ratio of the engine can be varied by rising and lowering the bore and the head of the engine with the help of handle mounted at the head of the engine. As the bore and the head of the engine are raised and lowered, the clearance volume is changed resulting in the change in the compression ratio. Water circulation is controlled by orifice type flow meter. The high rate of circulation of cooling water ensures a uniform temperature in the head. The view of the experimental setup and instrumentation are depicted in the fig 5. The load was displayed digitally in kg through the load signal sent by the load sensor fitted with the eddy current dynamometer. To measure the flow of water to the engine and calorimeter, rotameters were provided. Six type-K thermocouples were installed at different locations in the set-up for measuring water and exhaust gas temperature. Burette method was used to measure the volumetric flow rate of diesel. Governor was used to keep the engine rpm constant while varying the load on engine for creation of various test results.

Table 2 Properties of Tested Fuels

S.N	Properties	ASTM standard	Diesel	B100
1	Specific gravity, at15°C	-	0.829	0.896
2	Kinematic Viscosity, at 40°C, cSt	<5	2.570	5.800
3	Density, at 15°C, kg/m^3	-	828.100	895.700
4	Flash Point, °C	>130	78.000	162.000
5	Fire Point, °C	>53	85.000	173.000
6	Cloud point, °C	-3 to 12	<10	-3
7	Calorific value (MJ/kg)	>35.00	44.680	40.610
8	Cetane number	40 to 55	51.000	52.300

3.1 Methodology

The experimental investigation of the performance of the variable compression ratio engine was divided in two steps. In first step a series of tests were carried out to evaluate the engine performance while it was to be run on pure diesel. In second step a series of tests were carried out to evaluate the engine performance while it was to be run on cottonseed biodiesel blend. Four different blends of biodiesel were tested and optimized during this investigation, the different blends of biodiesel and diesel with notations are B10, B15, B20, & B25. For both steps, engine load was varied from zero to full load condition and compression ratio varies from 14 to 18. All relevant data viz. Brake specific fuel consumption (BSFC), Brake thermal efficiency (BTE), Break power and Exhaust gas temperature were recorded. Test sets were prepared for 0, 3, 6, 9, 12 and 15 kg load conditions. To measure BSFC and BTE at each load condition, time taken for 10 ml of fuel consumed was noted using a stopwatch. All readings were taken three times and an average of the three readings was taken for the results to increase the statistical confidence of the findings. Different graphs were plotted for various conditions for BSFC & BTE and results were analyzed.

1. Kirloskar Engine 2. Eddy Current Dynamometer
3. Control Panel 4. Injector
5. Fuel pump 6. Fuel tank (Diesel)
7. Fuel tank (Bio-Diesel) 8. Air stabilizer tank
9. Air filter 10. Calorimeter

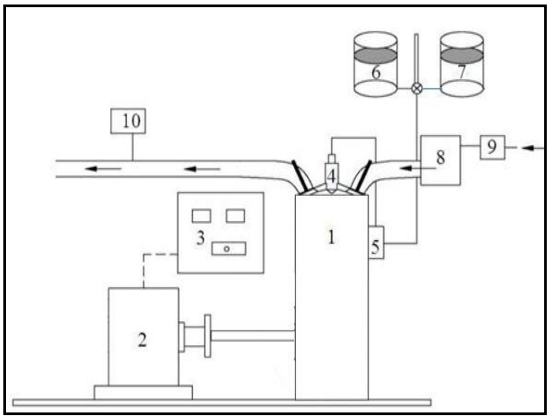

Figure 5 : Schematic Layout of Experimental Setupe

3. RESULT AND DISCUSSION

The experimental investigations are carried out using the above said biodiesel and their blends on the test engine. The detailed analyses of these results of engine performance are discussed in this section.

Table 3 : Technical Specifications of The Test Engine

Description	Specifications
Make	Technical Teaching Equipment , Bangalore (India)
Type	Vertical/Single acting, variable compression ignition diesel engine.
Power	3.67kW
Rated Speed	1500 rev/min (Governed Speed)
Number of Cylinders	1 cylinder
Compression Ratio	14 to 18 (Variable Compression Ratio)
Bore* Stroke	87.5 mm*110 mm
Method of Loading	Eddy Current Dynamometer
Method of Starting	Manual Crank/Self Start
Over all Dimensions	1300 x 1200 x 1050 mm
Air Tank Size (mm)	90(H) x 195(W) x 240(D)

4.1. Brake Thermal Efficiency

Brake thermal efficiency gives an idea of the output generated by the engine with respect to the heat supplied in the form of fuel. Generally, increasing the compression ratio improves the efficiency of the engine because of reduced heat loss and increased in brake power with increasing load. This improvement in performance of the engine at higher compression ratio is due to the reduced ignition delay [6]. Fig. 2 shows the variation of maximum BTE's obtained for different blends of cottonseed biodiesel and diesel at different compression ratios (i.e. 14, 15, 16, 17 & 18) respectively for 75% of full load (i.e. 12kg) reason for this is increase in friction losses at full load condition [7] and compared with diesel.

It is clearly observed from following figure 6, that diesel is having higher BTE compared to all blends of biodiesel at all compression ratios also the BTE increases with increase of compression ratio for all test blends, because as the compression ratio increases the temperature of compressed air inside the combustion chamber increases, the heat produced by the burning of fuel will also increase and since the available heat inside the chamber is increased which causes increase in useful energy produced by engine and hence BTE will increase [8]. The test results also indicate that the B20 gives maximum BTE among all blends and has a maximum value for compression ratio 18. The value of BTE for biodiesel blends is closest to diesel at compression ratio 17 for blend B20.

4.2 Brake Specific Fuel Consumption

The brake specific fuel consumption is termed as the mass of fuel consumed to produce unit brake power. Fig. 7 shows the variation of minimum brake specific fuel consumptions obtained at 75% of full load (i.e. 12kg) due to the reduction in net power because of increased friction losses at full load condition [9] for different blends of cottonseed biodiesel and diesel at different compression ratios (i.e. 14, 15, 16, 17 & 18) respectively and compared with diesel. It is clearly observed from following figure that diesel is having lower BSFC as compared to all blends of biodiesel-diesel at all compression ratios. Following figure also shows that minimum value of BSFC is obtained at B20 among all biodiesel-diesel blends this is probably due to availability of oxygen in the molecules of biodiesel (i.e. methyl ester of the oil), increases the combustion efficiency of the fuel by participating the combustion process and increases the power output, thus lesser fuel required for producing same power output [10].

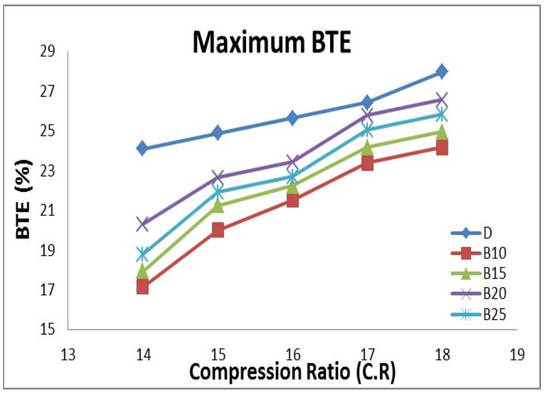

Figure. 6 : Maximum Brake Thermal Efficiency vs. C.R.

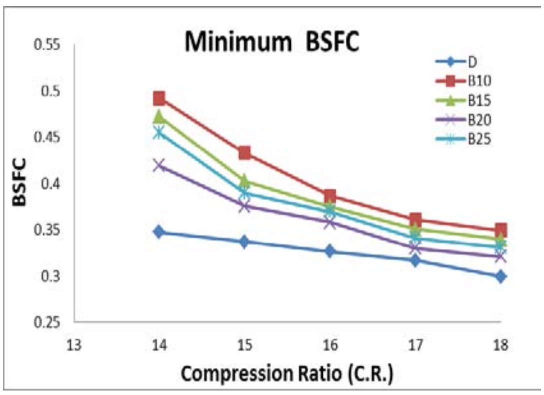

Figure. 7 : Minimum Brake specific fuel consumption Vs. C.R.

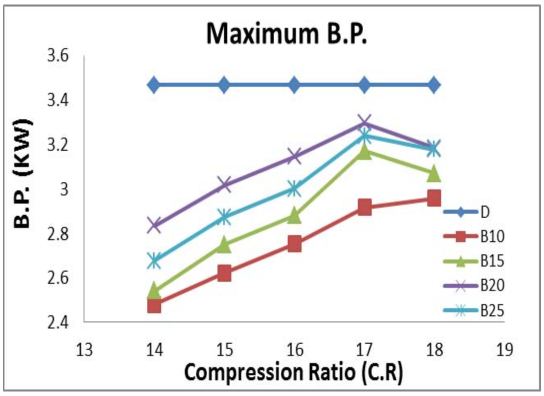

Figure 8 : Maximum Brake Power Vs. C.R.

The test results also indicates that the BSFC is higher at B25 as compared to B20 because when the mass percentage of oxygen contained by biodiesel exceeds beyond a certain limit, then mixture becomes lean which leads to incomplete combustion and hence the fuel consumption for producing same power output is increased, hence B20 gives minimum BSFC for above compression ratios [11].

It is observed from figure 3, that diesel is having minimum BSFC compared to all blends for all compression ratios, It can be observed from the figure that the BSFC for all cases reduced with increment in compression ratios as compression ratio increases the temperature of compressed air inside the combustion chamber increases, the heat produced by the burning of fuel will also increase and since the available heat inside the chamber is increased which causes increase in useful energy produced by engine and hence fuel required will decrease with compression ratio [12]. It also indicate that the B20 gives minimum BSFC for compression ratio 18 among all test blends and is very close to that of diesel at CR= 17 as compared to other blends.

4.3 Comparison of Brake Power:

For biodiesel Brake Power is calculated by assuming same fuel consumption at all respective load and compression ratio is same as taken for diesel. Fig. 4 shows the variation in maximum brake power at full load at different compression ratios for diesel and different blend, the brake power is maximum at full load because applied torque increase with load and brake power is a strong function of applied torque [13]. From the following figure it can be seen that pure diesel has highest brake power as diesel has more calorific value than the biodiesel. But among all diesel blends maximum brake power obtained at B20 blend because efficient combustion take place at this blend due to availability of extra oxygen molecule with biodiesel molecule than B25 due to leaning effect [9]. It also shows that the brake power increases with increase in the compression ratio because at higher compression there is larger expansion stroke for same amount of heat energy available in the combustion chamber. Due to this more heat energy converted into mechanical power that is brake power [14]. It also shows that B.P. increases up to compression ratio 17 and then decreases due to decrease in BTE at full load condition as discussed above.

It also observed that the B20 gives minimum BSFC for compression ratio 18 among all test blends and is very close to that of diesel at CR= 17 as compared to other blends.

4.4 Exhaust Gas Temperature

The variation of exhaust gas temperature with engine loads for the different blends of cottonseed biodiesel and diesel is shown in following figure 5, exhaust gas temperature is increase with an increase in the engine load and it is observed through the operation for all tested fuel, because of more fuel requirement for that extra power to take up the additional loading [15]. As mass flow rate of fuel increases in the combustion chamber of engine this leads to more heat available due to the burning of extra fuel, increased heat available and increases the temperature of exhaust gases [16]. The maximum exhaust gas temperature noticed at full load condition for all tested fuel and the maximum temperatures measured at full load condition are as 3700C, 3730C, 3740C, 3780C and 3890C for pure diesel, B10, B15, B20, and B25 respectively at compression ratio 14. Above results show that EGT increases with increase in concentration of Biodiesel in the blends and maximum exhaust temperature is 389°C at B25, the value viscosity is directly proportional to the concentration of biodiesel present in the blends and this increase of viscosity affects the fuel atomization, vaporization and combustion [17].

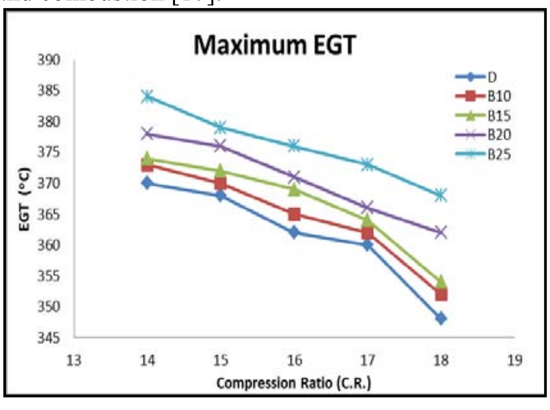

Figure 9 : Maximum Exhaust Gas Temperature Vs. C.R.

4. CONCLUSION

The performance characteristics of a four- stroke single cylinder, direct injection, VCR engine having power output of 3.67 kW, fueled with diesel, B10, B15, B20, and B25 blends have been analyzed and compared it at different compression ratios 14, 15, 16, 17, & 18 with those of diesel. Following conclusions can be drawn from the study:

(a) Highest thermal efficiency and lowest break specific fuel consumption are found for B20 (20% cottonseed + 80% diesel) blend among all other blending combination at different compression ratios.
(b) B20 gives better results than other blends so it is an optimized blend when the compression ratio varies from 14 to 18.
(c) Among all blend maximum break power was found for B20 blend at compression ratio 17 at full load (15 kg).
(d) Maximum Exhaust gas temperature was decreased with the increase of compression ratio for pure diesel and all diesel blend combinations.
(e) Maximum Exhaust gas temperature was found for B25 blend among diesel and all blend combinations at compression ratio 14 at full engine load.

REFERENCES

[1] S.L. Soni, D. Sharma, D. Sonar, N. L. Jain Anmesh Kumar Srivastava, "Effect of compression ratio on performance, emission and combustion characteristics of diesel–acetylene-fuelled single-cylinder stationary CI engine," Clean Techn Environ Policy, (2017), 19, 1361-1367.

[2] S.L. Soni, D. Sharma, A.K. Srivastava, M.P. Poonia, H.Jain N. L. Jain, "Performance and emission characteristics of preheated and blended thumba vegetable oil in a compression ignition engine," Applied Thermal Engineering, (2017), 113, 970-979.

[3] D. Maheswar, and K. Vijaya Kumar Reddy A. Siva Kumar, "Comparision of diesel engine performance and emissions from neat and transesterified cotton seed oil," Journal of Mechanical and Industrial Engineering, (2009), 3, 190-197.

[4] T. AlShemmeri, P. Eames, McMullan, J. N. Hewitt, and Y. S. Huang Rezvani Y. D. Wang, "An experimental investigation of the performance and gaseous exhaust emission of a diesel engine using blends of a vegetable oil," Applied Thermal Engineering, (2006), 26, 1684-1691.

[5] Md. Mustafizur Rahman, Md. Shamim Akhter Md. Nurun Nabi, "Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions," Applied Thermal Engineering, (2009), 29, 2265–2270.

[6] V. Singla, P. Gaikwad, and G. Sharma V. Bhardwaj, "Study of Performance Characteristics of Compression Ignition Engine Fuelled with Blends of Biodiesel from Used Cottonseed Oil," International Review of Applied Engineering Research, (2014), 4, 289-296.

[7] P. R. Kumar K. D. Kumar, "Experimental Investigation of Cotton Seed Oil and Neem Methyl Esters as Biodiesel on CI Engine," International Journal of Modern Engineering Research, (2012), 02, 1741-1746.

[8] Prof. V. Pandu Rangadu Dr V. Naga Prasad Naidu, "Experimental Investigations on a four stoke Diesel engine operated by Cotton seed biodiesel blended with Diesel," International Journal of Engineering and Innovative Technology, (2014), 03, 255-58.

[9] S. Kirankumar, "Combustion Characteristics Of Diesel Engine By Using Cotton Seed Oil," International Journal of Engineering Trends and Technology, (2013), 05, 47-53.

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

[11] R.Manimaran R. Senthil Kumar, "Performance and Emission Characteristics on 4-Stroke Single Cylinder C. I. Engine Using Cottonseed Bio Fuels," Asian Journal of Engineering Research, (2013) 01, 01-03.

[12] Anil Gandamwad ,Mayur Bawankure Shyam Kumar Ranganathan, "Performance evaluation of C.I. engine with cotton seed oil," Applied Thermal Engineering, (2011), 31, 350–354.

[13] D.C. Rakopoulos, "Heat release analysis of combustion in heavy-duty turbocharged diesel engine operating on blends of diesel fuel with cottonseed or sunflower oils and their bio-diesel," Fuel, (2012), 96, 524-534.

[14] H.E.Saleh, "The preparation and shock tube investigation of comparative ignition delays using blends of diesel fuel with bio-diesel of cottonseed oil," Fuel, (2011), 90, 421-429.

[15] Nitin M.Sakhare, SubhashLahane Pankaj S.Shelke, "Investigation of Combustion Characteristics of a Cottonseed Biodiesel Fuelled Diesel Engine," Procedia Technology, (2016), 25, 1049-1055.

[16] L.R. Ganapathy Subramanian, G. Manikandaraja V. Mathan Raj, "Experimental study of effect of isobutanol in performance, combustion and emission characteristics of CI engine fuelled with cotton seed oil blended diesel," Alexandria Engineering Journal, (2018), 57(3), 1369-1378.

[17] Jacob Powell, Calvin Parnell Sergio C. Capareda, "Engine performance and exhaust emissions of cottonseed oil biodiesel," in 2008 Beltwide Cotton Conferences, Nashville, Tennessee, (2008), 556-562.