Optimization of Injection Pressure and Injection Timing of a Diesel Engine Fuelled with Optimized Blend of B25 Cotton Seed Oil Biodiesel

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Abstract

Globally the demand for diesel and petrol is alarming due to speedy depletion of fossil fuel and hyper increase of automobiles in the current years. It results in seeking an alternate for fuel that led to many findings of alternative fuels. The previous researchers have exposed the utility of vegetable oils for engines as an alternative for diesel fuel. However, there is a constraint in using vegetable oils in diesel engines due to their high viscosity and low volatility. In this study, raw cotton seed oil is converted into biodiesel (Methyl Ester of Cotton Seed Oil) through transesterification process and finds the impact of injection pressures (190, 200, 210, 220 and 230 bar) and injection timings (21^o, 23^o and 25^o bTDC) on combustion, performance and emission parameters of optimized blend (B25) of cotton seed oil biodiesel with diesel in a single cylinder diesel engine. From the investigation, it is found that in a diesel engine the optimum injection pressure is 200 bar and injection timing is 23^o bTDC for the optimized blend of B25 cotton seed oil biodiesel and could be used as an alternative fuel with no modification of the diesel engine.

Keywords - *Cotton seed oil biodiesel, injection pressure, injection timing, combustion, performance, emission.*

I. INTRODUCTION

In few decades crude oil reserves are estimated to last due to fast depletion and demand. India is importing crude petroleum and petroleum products from Gulf countries. Indian scientists searched for an alternate to diesel fuel to preserve the global environment and to withstand the economic crisis. As far as India is concerned because of its vast agro forestry base, fuels of bio origin can be considered to be ideal alternative renewable fuels to run the internal combustion engines. Vegetable oils from plants both edible, non-edible and methyl esters (Biodiesel) are used as an alternate source for diesel fuel. Biodiesel was found to be the best alternate fuel, technically, environmentall acceptable, economically competitive and easily available. There are more than 350 oil bearing crops that have been identified, among which only sunflower, soyabean, cottonseed, mango seed, rapeseed and peanut oils are considered as potential alternative fuels for diesel engines. Traditional oilseed feedstock for biodiesel production predominantly includes soyabean, rapeseed/canola, palm, corn, sunflower, cottonseed, peanut and coconut oil [1]. The long chain hydrocarbon structure, vegetable oils have good ignition characteristics, however they cause serious problems such as carbon deposits build up, poor durability, high density, high viscosity, lower calorific value, more molecular weight and poor combustion. These problems lead to poor thermal efficiency, while using vegetable oil in the engine. These problems can be rectified by different methods which are used to reduce the viscosity of vegetable oils. The methods are transesterification, dilution and cracking method [2]. The transesterification of vegetable oil gives better performance when compared to straight vegetable oil [3]. A brief literature review of research work carried out by various researchers is presented below.

Many researches are focused on non-edible oils which are not suitable for human consumption due to the presence of toxic components present in the oil. Moreover, the non-edible oil crops grow in waste lands which are not suitable to use as food [4,5]. The increase in brake thermal efficiency and lower in specific fuel consumption were observed in a diesel engine fuelled with Calophyllum Inophyllum (punnai) biodiesel and additives [6]. The diesel engine performance parameters were higher and lower in emissions while operating with B20 blend biodiesel [7]. Rakopoulos et.al.[8] studied the use of four straight vegetable oils like sunflower, cotton seed, olive and corn oils on mini-bus engine and reported that olive oil has very high content of the unsaturated oleic acid (one double carbon bond) and very low content of the unsaturated linoleic acid (two double carbon bonds), in contrast with the other three vegetable linoleic acids. Further, the cotton seed oil has the highest content of palmitic acid (saturated). These may play some role in the soot formation and oxidation mechanism. Saravanan et al. [9] reported that pure Mahua oil methyl ester (B100) gives the lower emissions as compared with neat diesel (B0) in a DI diesel engine.

The performance of diesel engine with rice bran oil methyl ester and its diesel blends resulted in increase of CO, HC and soot emissions and slight increase of NOx with increase in blends compared to diesel Also the ignition delay and peak heat release rate for RBME were lower for biodiesel and it was increased with increase in RBME blends [10]. Rajan et al [11] have investigated the performance of a diesel engine with internal jet piston using biodiesel and observed increase in brake thermal efficiency and decrease in CO and smoke emissions at full load, whereas NO_x emission is increased at full load compared to diesel fuel. Sharanappa et al [12] investigated the use of Mahua oil methyl ester and its diesel blends as an alternative fuel in a hevy duty diesel engine and observed that B20 blend gives better performance and lower emissions. The methyl ester of Thevetia peruviana seed oil (METPSO) results lower emission of CO, HC and higher NO_x as compared to that of diesel [13]. The cylinder peak Pressure of soyabean biodiesel is close to that of diesel and also the peak rate of pressure rise and peak heat release rate during premixed combustion are lower for biodiesel [14].

Implementation of biodiesel in India will lead to many advantages like green cover to waste land, support to agriculture, rural economy, reduction in dependence on imported crude oil and reduction in air pollution [15]. Currently, India is spending about Rs.80, 000 million per year for importing 70% of petroleum fuels and produces only 30% of the total fuel requirements. It is estimated that mixing of 5% of biodiesel fuel to the present diesel fuel can save Rs.40, 000 million per year. The objective of the present study is to find the optimum injection pressure and injection timing of a diesel engine for the optimized blend of B25 cotton seed oil biodiesel.

II. BIODIESEL PRODUCTION AND CHARACTERIZATION

A. Biodiesel Production Procedure

The production of biodiesel from cotton seed oil is done by transesterification process. It is the process of reacting the cotton seed oil with methanol in the presence of catalyst (KOH). During the process, the molecule of cotton seed oil is chemically broken to form methyl ester of cotton seed oil (biodiesel) and then the biodiesel is filtered to separate from glycerol. A maximum of 800 ml cotton seed oil biodiesel production is observed for 1 litre of raw cotton seed oil, 250 ml of methanol and 13 gm of potassium hydroxide at 60^{o}C.

B. Biodiesel Properties

A series of tests were conducted to characterize the properties and compositions of the produced biodiesel. The properties of cotton seed oil biodiesel biodiesel and its blends with diesel fuel are shown in **Table 1**. It is shown that the viscosity of biodiesel is evidently higher than that of diesel fuel. The density of the biodiesel is approximately 8.16% higher than that of diesel fuel. The gross calorific value is approximately 9.12% lower than that of diesel. Therefore, it is necessary to increase the fuel amount to be injected into the combustion chamber to produce the same amount of power. Fuels with flash point 52°C are regarded as safe.

Thus, biodiesel is an extremely safe fuel to handle when compared to diesel. B25 has a flash point much above that of diesel; making biodiesel a preferable choice as far as safety is concerned. With the increase of biodiesel percentage in blends, solidifying point of blends increases [16].

Table 1.Properties of cotton seed oil biodiesel in comparison with diesel

Property	Diesel	B 25	B 100
Specific gravity @ 15^{o}C	0.8290	0.8459	0.8965
Kinematic Viscosity @ 40°C in cSt	2.57	3.38	5.8
Density @ 15^{o}C (kg/m^3)	828.1	845	895.7
Flash point °C	53	81	162
Fire point °C	59	88	173
Gross Calorific Value (kJ/kg)	44,680	43,663	40,610
Cetane Number	51	51.3	52

III. EXPERIMENTAL SETUP

The performance tests were carried on a single cylinder, four stroke and air cooled Kirloskar TAF1 diesel engine and its specification are shown in **Table 2**. The layout of the experimental setup is shown in **Fig. 1**. An eddy current dynamometer was connected with the engine and used to measure engine power. An exhaust gas analyser MRU DELTA 1600-L was employed to measure NO_x, HC, CO, O_2 and CO_2 emission on line.

Table 2. Specifications of the test engine

Make and Model	:Kirloskar TAF 1
Type	:Four stroke, Compression ignition, air cooled, direct injection
Bore Stroke	:87.5 mm ×110 mm
Compression ratio	:17.5: 1
Swept volume	:661cm^3
Connecting rod length	:220 mm
Rated power	:4.4 kW
Rated speed	:1500 rpm
Start of injection	:23^o bTDC
Injection pressure	:200 bar

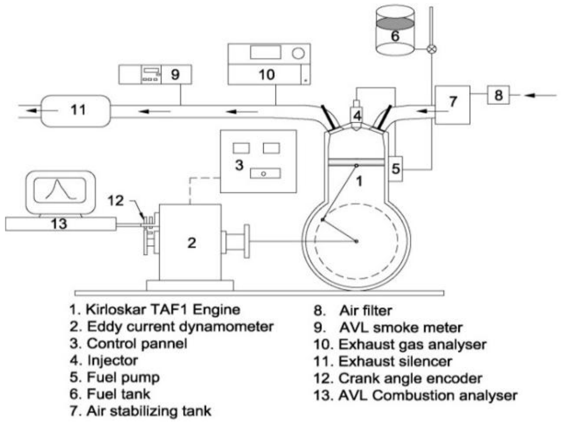

Fig. 1. Layout of experimental setup

The AVL smoke meter was used to measure the smoke density. Using AVL combustion analyser, the combustion parameters such as cylinder pressure and heat release rate were analysed at different injection pressure (190 bar, 200 bar, 210 bar, 220 bar and 230 bar) and at different injection timing (21^o, 23^o and 25^o bTDC) with B25 cotton seed oil biodiesel.

IV. RESULTS AND DISCUSSION

A. Variation of injection pressure

For the optimized blend (B25), the injection timing is kept constant and the injection pressure is varied for 190 bar, 210 bar, 220 bar and 230 bar respectively.

The variation of cylinder pressure with respect to crank angle is shown in fig 2. The peak pressure for B25 cotton seed oil biodiesel in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 69.59, 69.68, 69.93, 70.65 and 70.651 bar respectively. It is clear that increase in injection pressure increases the peak pressure and is close to static injection pressure.

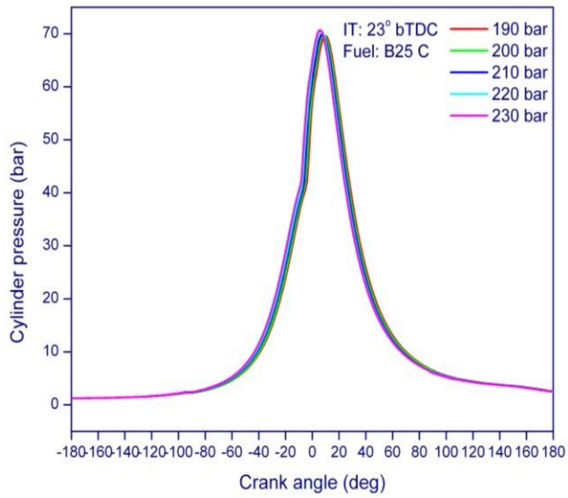

Fig. 2. Cylinder pressure with crank angle

The heat release rate at different injection pressure is shown in fig 3. The heat release rate for B25 cotton seed biodiesel in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 110.32, 111.75, 111.77, 112.09 and 112.88 kJ/m^{3}deg respectively. For 230 bar injection pressure, the heat release rate is higher compared to static and other pressures in the premixed combustion phase, whereas heat release rate is lower in the diffusive combustion. The reason may be, increase in injection pressure increases atomization and fine spray formation of fuel but may not find enough time to undergo complete combustion. From the graph, it is very clear that at 200 bar injection pressure the heat release rate is optimun in both premixed and diffusive combustion phase.

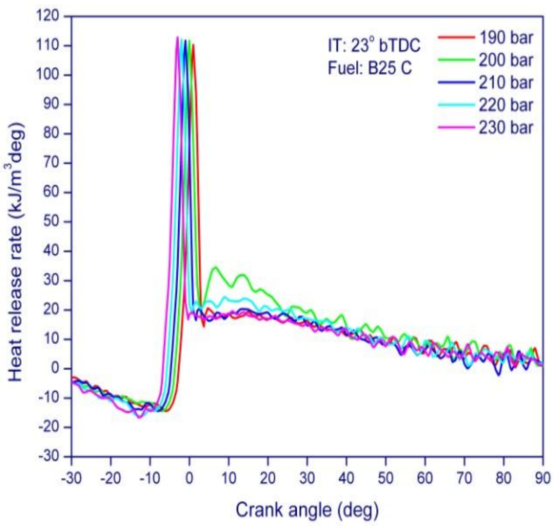

Fig. 3. Heat release rate with crank angle

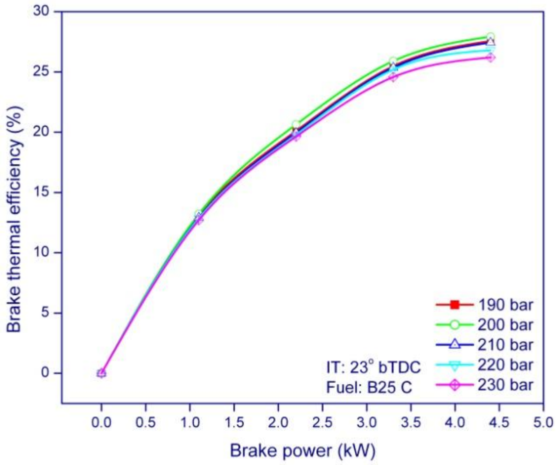

Fig. 4 Brake thermal efficiency with BP

The fig 4 shows the variation of brake thermal efficiency with respect to brake power. The brake thermal efficiency for B25 cotton seed oil biodiesel in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 27.56, 27.92, 27.44, 26.8 and 26.2% respectively. The BTE is maximum at 200 bar and this is due to fine spray formed during injection and improved atomization. Further increase in IP pressure tends to decrease BTE; this may be due to higher IP the size of fuel droplets decreases and very high fine fuel spray will be injected, because of this penetration of fuel spray reduces and momentum of fuel droplets will be reduced [17].

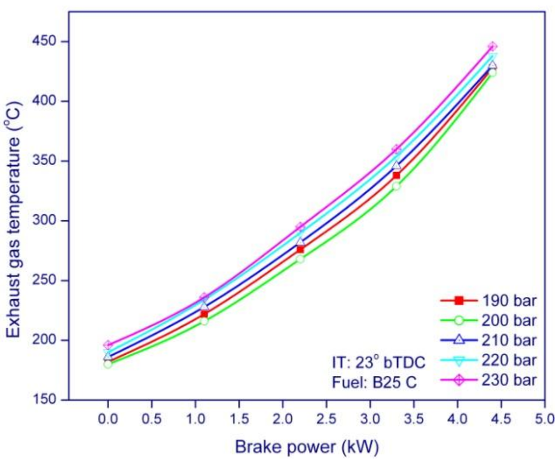

Fig. 5. Exhaust gas temperature with BP

The variation of exhaust gas temperature with respect to brake power is shown in fig 5. The exhaust gas temperature for B25 cotton seed oil biodiesel in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 428^o, 424^o, 430^o, 438^o and 446^{o}C respectively. By increasing injection pressure, the exhaust gas temperature is increased and this could be due to lower heat transfer rate at high injection pressures which is evident from the trends of BTE.

The variation of NO_x with respect to brake power is shown in fig 6. The emission of NO_x for B25 cotton seed oil biodiesel in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 816, 810, 821, 834 and 848 ppm respectively. The NO_x formation increases and attains maximum at full load. This may be due to higher combustion temperature inside the cylinder at full load. As NO_x formation is a strong temperature dependent phenomenon; it is directly related to the exhaust gas temperature and it is inversely related to smoke and CO. From the graph, it is clear that increase in injection pressure increases the NO_x emission at full load whereas for B25 at 200 bar NO_x emission is optimal.

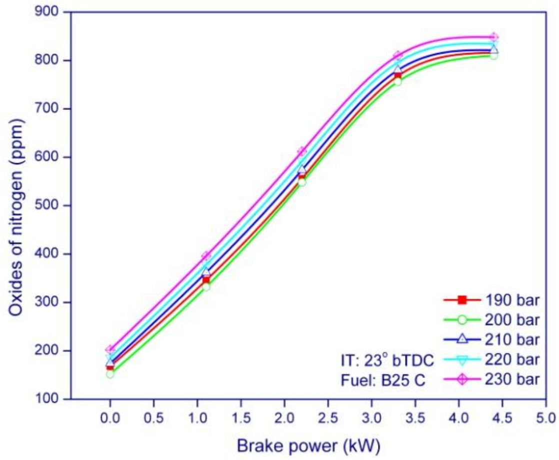

Fig. 6. Oxides of nitrogen with BP

The variation of smoke density with respect to brake power is shown in fig 7. The emission of smoke for B25 cotton seed oil biodiesel in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 41.4, 40.8, 39.7, 37.6 and 34.7 HSU respectively. It is evident that the increase in injection pressure reduces the smoke emission. The smoke emission obtained in this study follows the trend as reported by [18].

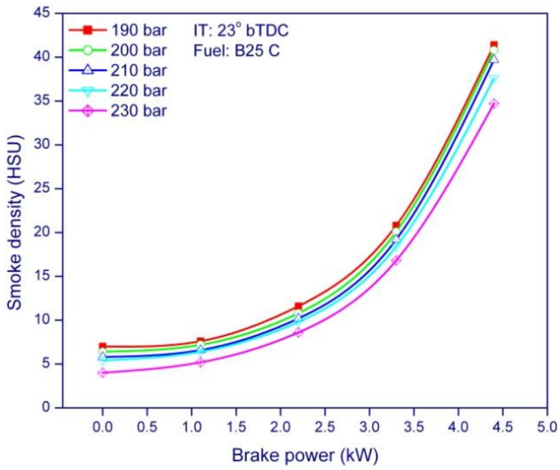

Fig. 7. Smoke density with BP

C. Variation of injection timing

For the optimized blend (B25), the injection pressure (200 bar) is kept constant and the injection timing is varied to advance (25^o bTDC) and retardation (21^o bTDC).

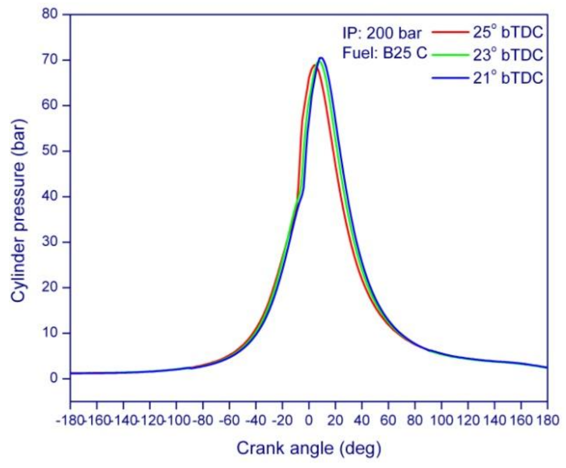

Fig. 8. Cylinder pressure with crank angle

The variation of cylinder pressure with respect to crank angle is shown in fig 8. The peak pressure for B25 cotton seed oil biodiesel in 21^o, 23^o and 25^o bTDC with injection pressure of 200 bar is 70.51, 69.67 and 68.88 bar respectively. It is evident that retarding the injection timing shows increase in the peak pressure than static and advance injection timings as reported by Chandrakasan solaimuthu et al., [19].

The heat release rate at different injection timing is shown in fig 9. The heat release rate for B25 cotton seed oil biodiesel in 21^o, 23^o and 25^o bTDC with injection pressure of 200 bar is 111.82, 111.75 and 90.12 kJ/m^3deg respectively. The heat release rate is higher for retard injection timing but very closer to static injection timing. The heat release rate obtained in this study follows the same trend as reported by Chandrakasan solaimuthu et al., [19].

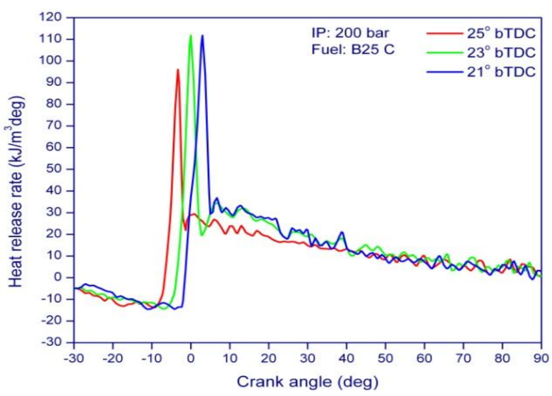

Fig. 9. Heat release rate with crank angle

The variation of brake thermal efficiency with respect to brake power is shown in fig.10. The brake thermal efficiency for B25 cotton seed oil biodiesel in 21^o bTDC, 23^o bTDC and 25^o bTDC with injection pressure of 200 bar is 28.4, 27.92 and 27.32% respectively. The result shows that there is an increase of 1.7% the brake thermal efficiency for injection timing 21^o bTDC than static injection timing whereas advancing injection timing is not desirable as it leads to drop in BTE of the engine. The BTE obtained in this study follows the same trend as reported by Jindal [20].

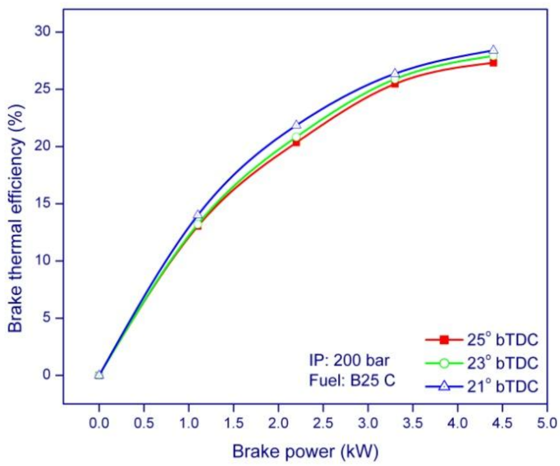

Fig. 10. Brake thermal efficiency with BP

The variation of exhaust gas temperature with respect to brake power is shown in fig 11. The exhaust gas temperature for B25 cotton seed oil biodiesel in 21^o, 23^o and 25^o bTDC with injection pressure of 200 bar is 436^o, 424^o and 413^o C respectively. As combustion is delayed, more heat is released in mixing controlled combustion phase; so that greater amount of heat goes with exhaust gases. With advanced injection, wall heat transfer is more due to earlier combustion in the cycle leading to lower exhaust temperature.The exhaust gas temperature for injection timing 21^o bTDC is higher than static and advance injection timings. The EGT obtained in this study follows the same trend as reported by Dilip Sutraway et al., [21].

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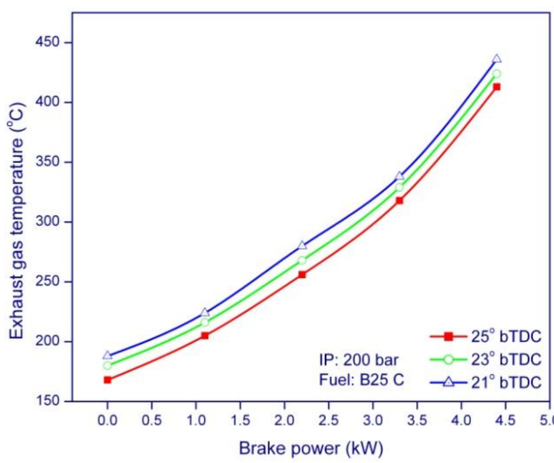

Fig. 11. Exhaust gas temperature with BP

The variation of NO_x with respect to brake power is shown in fig 12. The emission of NO_x for B25 cotton seed oil biodiesel in 21^o, 23^o and 25^o

bTDC with injection pressure of 200 bar is 792, 810 and 846 ppm respectively. Jindal [22] reported that advancement of injection time enhances the NO_x emission whereas retarding the injection helps to reduce the same. From the graph, it is clear that advance in injection timing increases the NO_x emission than static and retard injection timings.

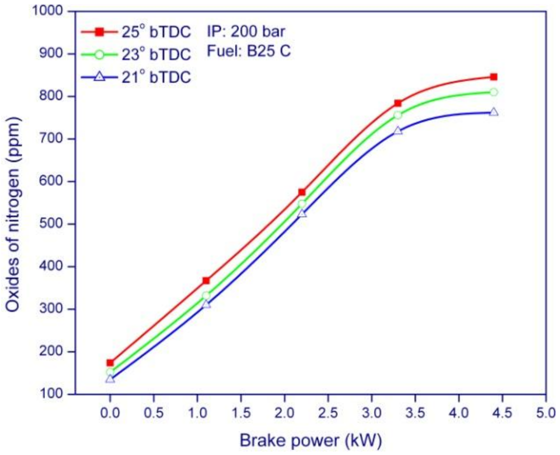

Fig. 12. Oxides of nitrogen with BP

The variation of smoke density with respect to brake power is shown in fig 13. The emission of smoke for B25 cotton seed oil biodiesel in 21°, 23° and 25° bTDC with injection pressure of 200 bar is 42.9 , 40.8 and 38.6 HSU respectively. The experimental results show that the smoke emission increases when the injection timing is retarded and decreases when the injection timing is advanced. The increase in smoke emission when retarded may be due to poor atomization and combustion because of higher viscosity of the blend [23].

From the results, it is clear that there is increase of 5.15% smoke emission by the retardation of injection timing and decrease of 5.4% smoke emission when the injection timing is advanced. Hence optimum injection timing would be 23° bTDC.

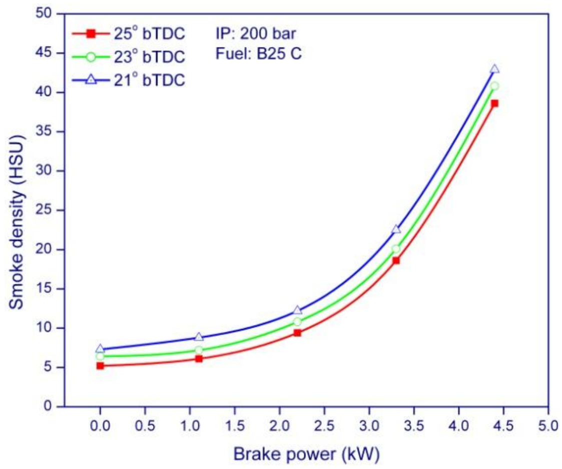

Fig. 13. Smoke density with BP

V. CONCLUSION

In this investigation, it is concluded that 200 bar and 23° bTDC would be the optimum injection pressure and injection timing which gives better combustion, performance and lower emissions when compared to other injection pressures and injection timings. So, B25 cotton seed oil biodiesel could be used as an alternative fuel for diesel engine with injection pressure of 200 bar and injection timing of 23° bTDC with no engine modifications.

REFERENCES

[1] Sylvester C.Izah and Elijah I.Ohimain, 2013, The challenge of biodiesel production from oil palm feedstock in Nigeria. Greener journal of Biological sciences, 3 (1); 001-012.
[2] Sandeep Singh, 2012. Study of various methods of biodiesel production and properties of biodiesel prepared from waste cotton seed oil and waste mustard oil. Thesis of M.E.in thermal engineering, Thapar University.
[3] Shereena, K.M. and T.Thangaraj, 2009. Biodiesel: An alternative fuel produced from vegetalbe oils by transesterification. Electronic journal of Biology, 3; 67-74.
[4] Dennis.Y.C. Leung, Xuan.Wu and M.K.H.Leung, A review on biodiesel production using catalysed transesterification, Applied Energy 87 (2010) 1083-1095.
[5] P.K.Devan and N.V. Mahalakshmi, A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil-eucalyptus oil blends, Applied Energy 86 (2009) 675-680.
[6] Avinash K Hegde and K.V. Sreenivas rao, Performance and emission study of 4S CI engine using Calophyllum Inophyllum biodiesel with additives, International Journal on Theoretical and Applied Research Mechanical Engineering 1 (2012) 1-4.
[7] Subhash Lahane and K.A. Subramanian, Impact of nozzle holes configuration on fuel spray, wall impingement and NOx emission of a diesel engine for biodiesel- diesel blend (B20), Applied Thermal Engg., 64 (2014) 307-314.
[8] Rakopoulos, C.G. Rakopouls, E.G.Giakoumis, A.M.Dimaratos and M.A.Founti, Comparative environmental behavior of bus engine operating on blends of diesel fuel with four straight vegetable oils of Greek origin: sunflower,cottonseed, corn and olive, Journal of Fuel 90 (2011) 3439-3446.
[9] N.Saravanan, G. Nagarajan and S. Puhan, Experimental investigation on a DI diesel engine fuelled with Madhuca Indica ester and diesel blend, Biomass and Bioenergy 34 (2010) 838-843.
[10] L.N.R.Gattamaneni, S. Sravanan, S.Sampath and K.Rajagopal, Combustion and emission characteristics of diesel engine fuelled with rice bran oil methyl ester and its diesel blends, Thermal sci., 12 (2008) 139-150.
[11] K.Rajan and K.R.S. Kumar, Performance and emission characteristics of DI ignition engine with biodiesel using internal jet piston, Environ. Stud., 64 (2010) 1982-1988.
[12] Sharanappa Godiganur, Suryanarayana Murthy and CH.Ranaprathap reddy, 6BTA 5.9 G2-1 Cummins engine performance and emission tests using methyl ester Mahua (Madhuca indica) oil/diesel blends, Renewable Energy 34 (2009) 2172-2177.
[13] T.Balusamy and R. Marappan, Comparative study of Thevetia Peruviana seed oil with other biofuels and diesel as fuel for CI engine, International Journal of Applied Engineering Research, 10 (2008) 93-100.
[14] D.H. Qi, L.M. Geng, H. Chen, Y.Z.H. Bian and J. Liu, Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil, Renewable Energy, 34 (2009) 2706-2713.
[15] S.Jain and M.P.Sharma, Biodiesel Production from Jatropha Curcas Oil, Renewable and Sust.Energy Reviews,14 (2011) 3140-47.

[16] Qi, D.H., L.M. Geng, H. Chen, Y.Z.H. Bian and J. Liu et al., 2009. Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil. Renew Energy, 34: 2706-2713.
[17] Honnegowda and Ramesha D.K. (2013), Effect of injection pressures on the performance and emission characteristics of CI engine with cotton seed oil methyl ester, International Journal of Innovative Research in Science Engineering and Technology, 2 No: 9; 4796-4802.
[18] Solaimuthu, C., P.Vetrivel, MR. Subbarayan and Channankaiah, 2014. Efffect of nozzle opening pressures on diesel engine fuelled with madhuca indica biodiesel and its blend with diesel fuel, Indian Journal of Engineering,7(17);14-22.
[19] Chandrakasan Solaimuthu and Palanisamy Govindarajan, 2012. Effect of injection timing on performance, combustion and emission characteristics of diesel engine using mahua oil methyl ester as fuel, Journal of Scientific and Industrial Research, 71; 69-74.
[20] Jindal.S, 2011. Effect of injection timing on combustion and performance of a direct injection diesel engine running on Jatropha methyl ester. International Journal of Engineering and Environment, 2(1); 113-122.
[21] Dillip Sutraway, Y.U.Biradar and V.V.Katti, 2014. Effect of fuel injection time on performance of CI engine using (Simarouba)biodiesel as fuel. Journal of Mechanical Engineering Research and Technology,2 (1);556-572.
[22] Jindal.S, 2010. Effect of engine parameters on NOx emissions with Jatropha biodiesel as fuel.International Journal of Engineering and Environment, 1(2); 343-350.
[23] Elango,T. and T.Senthilkumar, 2011.Performance and emission characteristics of CI engine fuelled with non-edible vegetable oil and diesel blends, Journal of Engineering Science and Technology, 6; 240-250.