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Experimental Investigation for Various Injection Pressure and Injection Timing of a Diesel Engine using B25 Methyl Ester of Mango Seed Oil

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Abstract

The world's rapid depletion of petroleum resources and increased number of automobiles in recent years has resulted in great demand for diesel and petrol. The search for an alternate fuel has led to many findings due to which a wide variety of alternative fuels are available at our disposal now. The existing studies have revealed the use of vegetable oils for engines as an alternative for diesel fuel. However, there is a limitation in using straight vegetable oils in diesel engines due to their high viscosity and low volatility. In the present work, neat mango seed oil is converted into their respective methyl ester through transesterification process and presents the effect of injection pressures (190, 200, 210, 220 and 230 bar) and injection timings (21^o, 23^o and 25^o bTDC) on performance, emission and combustion characteristics of best blend (B25) of methyl ester of mango seed oil with diesel in a single cylinder, four stroke vertical and air cooled Kirloskar diesel engine. From the experimental investigation, it is concluded that B25 could be used as an alternative fuel for diesel engine with the static injection timing of 23^o bTDC with injection pressure of 200 bar without any engine modifications.

Keywords: Methyl ester of mango seed oil, injection pressure, injection timing, performance, emission, combustion

1. INTRODUCTION

Crude oil reserves estimated to last for few decades due to their 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, environmentally 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 and 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 NO_x 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 and Kumar [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 optimized injection pressure and injection timing for the best blend (B25) of methyl ester of mango seed oil with respect to performance, emission and combustion characteristics of a diesel engine.

2. BIODIESEL PRODUCTION AND CHARACTERIZATION

2.1. Biodiesel Production

The production of biodiesel from mango seed oil is done by transesterification process. It is the process of reacting the mango seed oil with methanol in the presence of catalyst (KOH). During the process, the molecule of mango seed oil is chemically broken to form methyl ester of mango seed oil (biodiesel) and then the biodiesel is filtered to separate from glycerol. A maximum of 850 ml methyl ester of mango seed oil production is observed for 1 litre of raw mango seed oil, 250 ml of methanol and 12 gm of potassium hydroxide at 60^oC.

2.2. Biodiesel Properties

A series of tests were conducted to characterize the properties and compositions of the produced biodiesel. The properties of 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% higher than that of diesel fuel. The gross calorific value is approximately 8.5% 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 [14].

Table .1 Properties of biodiesel in comparison with diesel (Source: Evaluation at Eta-lab, Chennai)

Property	**Diesel**	**B 25**	**B 100**
Specific gravity @ 15^{o}C	0.829	0.846	0.895
Kinematic Viscosity @ 40°C in cSt	2.57	3.33	5.6
Density @ 15^{o}C (kg/m^3)	828	845	894
Flash point °C	53	82	168
Fire point °C	59	88	174
Gross Calorific Value (kJ/kg)	44,680	43,729	40,874
Cetane Number	51	51.3	52

3. 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.

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.

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

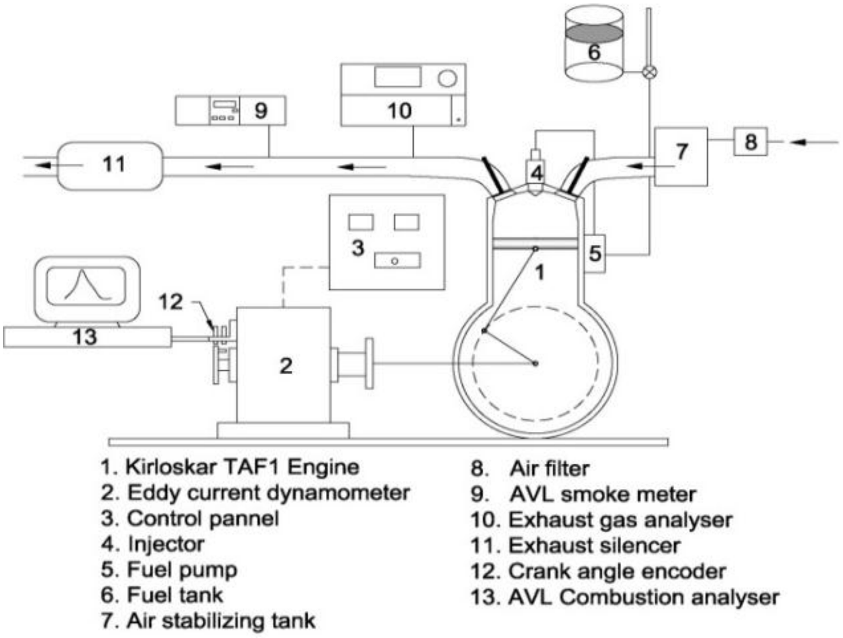

Figure 1. Layout of experimental setup

4. RESULTS AND DISCUSSION

4.1 Variation of injection pressure

In the static injection timing (23^{o}bTDC) and injection pressure (200 bar), B25 is the optimized blend compared to other blends [16]. Here for the best 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.

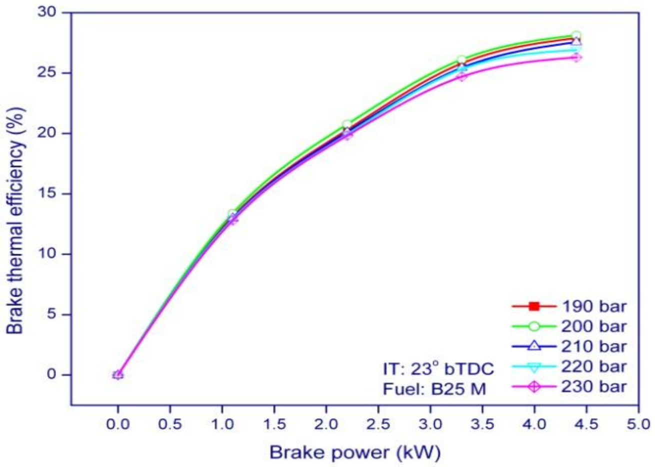

Figure 2. Brake thermal efficiency with BP

The Fig. 2 shows the variation of brake thermal efficiency with respect to brake power. The brake thermal efficiency for B25 MEMSO in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 27.90, 28.13, 27.56, 26.9 and 26.3% 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].

The variation of exhaust gas temperature with respect to brake power is shown in Fig. 3. The exhaust gas temperature for B25 MEMSO in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 430^o, 425^o, 432^o, 440^o and 448^{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.

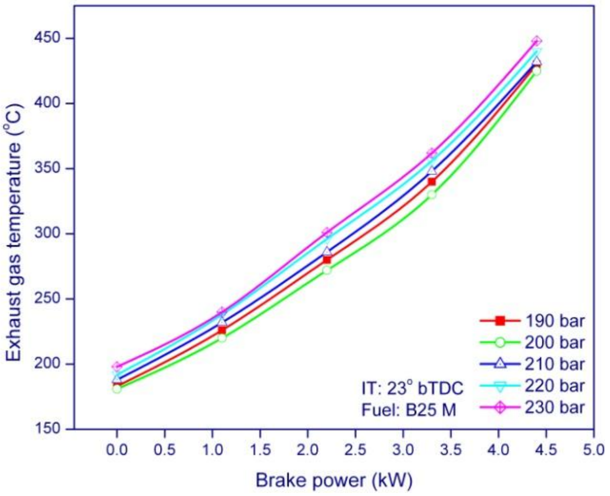

Figure 3 . Exhaust gas temperature with BP

The variation of NO_x with respect to brake power is shown in Fig. 4. The emission of NO_x for B25 MEMSO in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 834, 828, 839, 851 and 865 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.

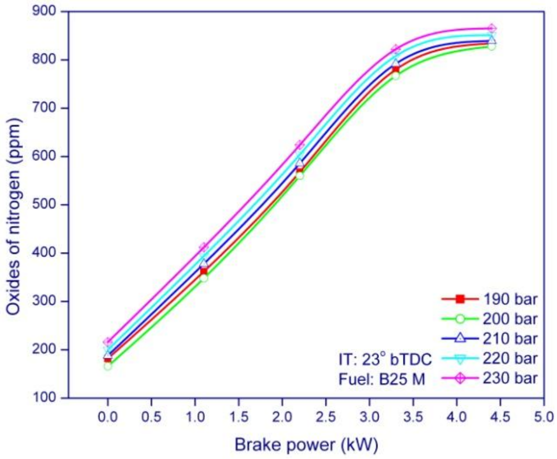

Figure 4. Oxides of nitrogen with BP

The variation of smoke density with respect to brake power is shown in Fig. 5. The emission of smoke for B25 MEMSO in 23^o bTDC with 190, 200, 210, 220 and 230 bar is 41.2, 40.4, 39.2, 37.4 and 34.6 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 Solaimuthu et al [18].

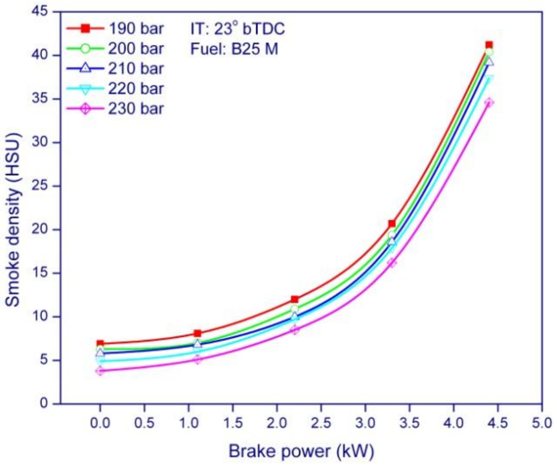

Figure 5. Smoke density with BP

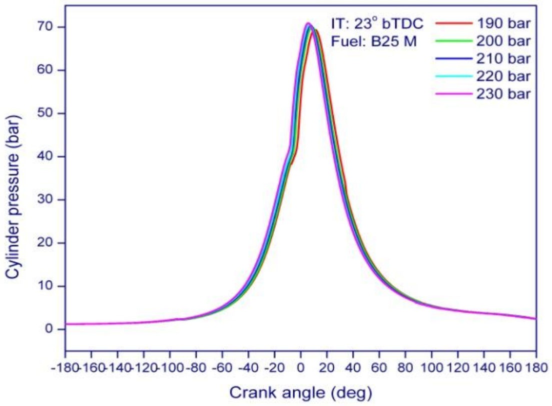

Figure 6. Cylinder pressure with crank angle

The variation of cylinder pressure with respect to crank angle is shown in Fig. 6. The peak pressure for B25 MEMSO in 23^{o} bTDC with 190, 200, 210, 220 and 230 bar is 69.41, 69.98, 70.35, 70.46 and 70.93 bar respectively. It is clear that increase in injection pressure increases the peak pressure and is close to static injection pressure.

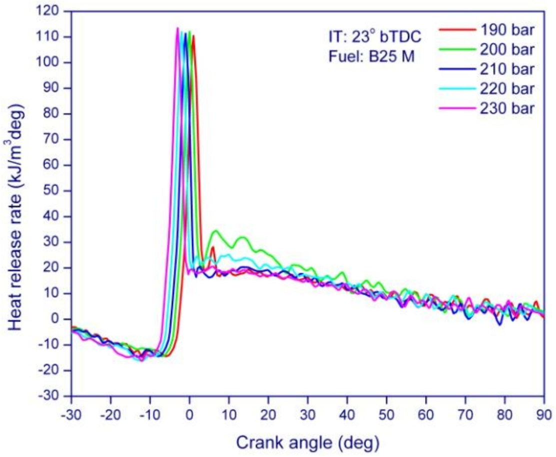

Figure 7. Heat release rate with crank angle

The heat release rate at different injection pressure is shown in Fig. 7. The heat release rate for B25 MEMSO in 23^{o} bTDC with 190, 200, 210, 220 and 230 bar is 110.44, 112.12, 111.34, 112.02 and 113.47 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.

4.2 Variation of injection timing

Here for the best blend B25, the injection pressure (200 bar) is kept constant and the injection timing is varied to advance (25° bTDC) and retardation (21° bTDC).

The variation of brake thermal efficiency with respect to brake power is shown in Fig. 8. The brake thermal efficiency for B25 MEMSO in 21° bTDC, 23° bTDC and 25° bTDC with injection pressure of 200 bar is 28.8, 28.13 and 27.7% respectively. The result shows that there is an increase of 2.38% the brake thermal efficiency for injection timing 21°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 [19].

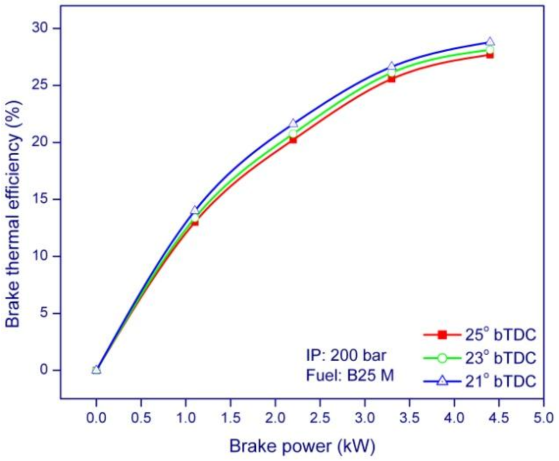

Figure 8. Brake thermal efficiency with BP

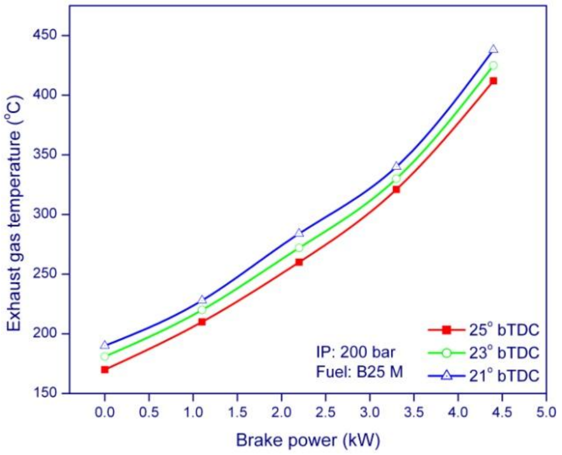

Figure 9. Exhaust gas temperature with BP

The variation of exhaust gas temperature with respect to brake power is shown in Fig. 9. The exhaust gas temperature for B25 MEMSO in 21°, 23° and 25° bTDC with injection pressure of 200 bar is 438^o, 425^o and 412^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 [20].

The variation of NO_x with respect to brake power is shown in Fig. 10. The emission of NO_x for B25 MEMSO in 21^o, 23^o and 25^o bTDC with injection pressure of 200 bar is 782, 828 and 864 ppm respectively. Jindal [21] 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.

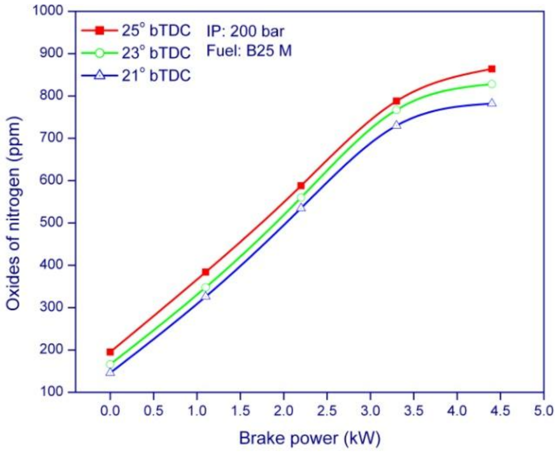

Figure 10. Oxides of nitrogen with BP

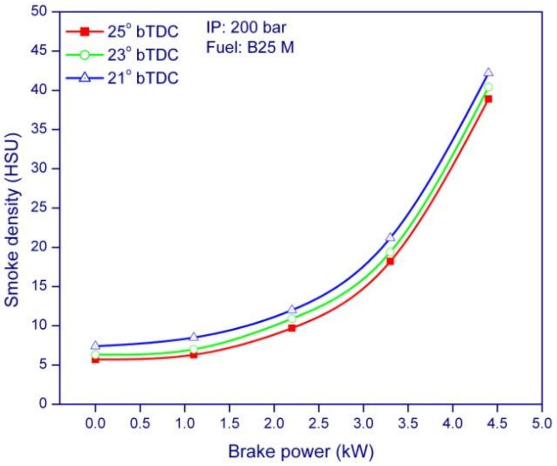

Figure 11. Smoke density with BP

The variation of smoke density with respect to brake power is shown in Fig. 11. The emission of smoke for B25 MEMSO in 21°, 23° and 25° bTDC with injection pressure of 200 bar is 42.2 , 40.4 and 38.9 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 [22]. From the results, it is clear that there is increase of 4.45% smoke emission by the retardation of injection timing and decrease of 3.7% smoke emission when the injection timing is advanced. Hence optimum injection timing would be 23° bTDC.

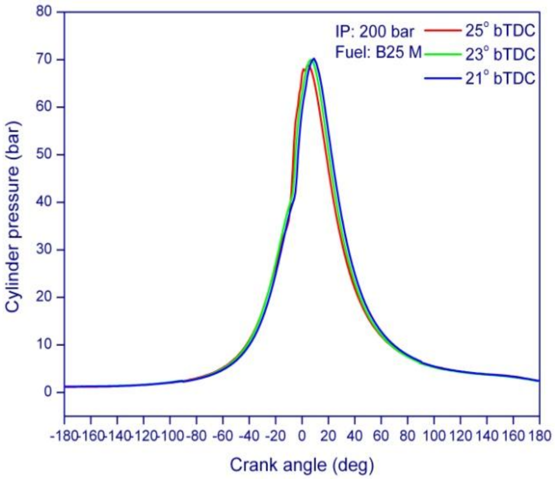

Figure 12. Cylinder pressure with crank angle

The variation of cylinder pressure with respect to crank angle is shown in Fig. 12. The peak pressure for B25 MEMSO in 21°, 23° and 25° bTDC with injection pressure of 200 bar is 70.24, 69.98 and 68.7 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.[23].

The heat release rate at different injection timing is shown in Fig. 13. The heat release rate for B25 MEMSO in 21°, 23° and 25° bTDC with injection pressure of 200 bar is 113.12, 112.24 and 93.45 kJ/m^{3}deg 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. [23].

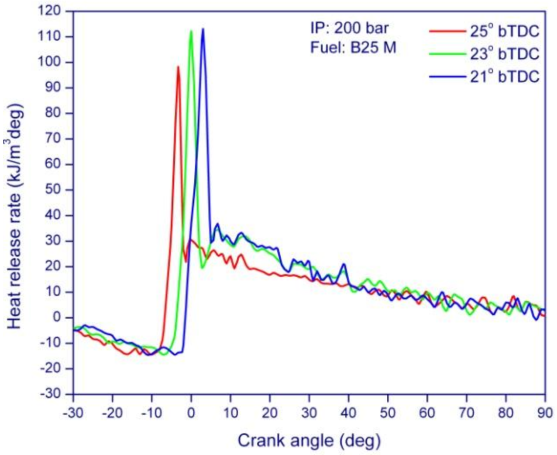

Figure 13. Heat release rate with crank angle

5. CONCLUSION

In the present investigation, it is concluded that 23^o bTDC with of 200 bar would be the optimum injection timing and injection pressure which gives better performance, combustion and lower emissions when compared to other injection timings and injection pressures. So, B25 MEMSO could be used as an alternative fuel for diesel engine with the static injection timing of 23^o bTDC with injection pressure of 200 bar without any engine modifications.

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