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An impact of different injection timing operating on chlorellea emersonii methyl ester (CEME) with best fuel (BF)

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Biodiesel is a clean-burning, oxygenated monoalkyl-ester fuel manufactured from natural, renewable sources like new/used vegetable oils and animal fats. The injection time has a significant impact on engine performance, particularly pollutant emissions. The purpose of this research is to see if Chlorellea Emersonii methyl ester (CEME) can be used as a fuel alternative in a compression ignition (CI) engine. The CEME was synthesised using a transesterification technique, and the engine parameters (performance, emission, and combustion) were investigated using 20 (v/v%) biodiesel blends at retard, standard, and advanced injection timings (IT). In this study an alteration in injection timing were done with TRC and BF combination. Other than conventional injection timing of 23°bTDC three more injection timing included ie 24°bTDC (advance IT), 21°bTDC (retarded IT) and 22°bTDC (retarded IT). Outcome results showed 22°bTDC(retarded IT) with 2.12% improvement in BTE followed by 24.5%,35.15% and 90.2% reduction in HC,CO and smoke.

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Keywords: Chlorellea emersonii methyl ester, Injection timing, Performance, Emission, Combustion

1. Introduction

Future economic growth is contingent on the long-term availability of energy supplies that are affordable, accessible, plentiful, and ecologically friendly. Petroleum-based fuels are the most important and widely used forms of energy to meet the world's growing energy demands. Rapid increases in petroleum usage exacerbated environmental damage by disrupting natural cycles. The rising awareness of environmental concerns and the overuse of fossil fuel sources led to the use of biofuels in CI engines, which has a direct influence on environmental circumstances. Because of its similarities to fossil diesel, biodiesel has acquired a lot of traction among the many biofuels that have been acknowledged. Several animal and plant-based feedstocks have been found that can be utilized to make biodiesel.

Hyung et.al investigated biodiesel in research diesel engine by varying injection timing and intake air temperature. Engine speed and fuel injection quantity fixed. Injection timine of 6°bTDC and 9°bTDC yielded high indicated mean effective pressure (IMEP) and reduced NOx and HC emission. Increase in intake air temperature resulted in better vaporization chances of fuel and ignition timing advanced near to top dead centre(TDC). Prolongation of combustion duration were also noted. Increase in intake air temperature from 20°C to 100°C caused increase in IMEP(0.39 to 0.41MPa) and THC reduced(0.85 to 0.51g/kwh) and CO reduced (3.72-1.34 g/kWh). Oxides of nitrogen increased slightly(3.69 to 4.82g/kwh). PM diameter increased and its number decreased.

Wang et.al conducted experiment in diesel engine with 25% pumpkin seed oil. Fuel properties were found based on ASTM standards. GC-MS analysis was done to check free fatty acid composition. Engine with 17.5:1 compression ratio and 210bar injection pressure was

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employed for study. Few retarding and advancement of injection timing were carriedout. Better performances were observed with IT of 25^{o}bTDC operating condition. Notable reeduction in CO,HC and smoke were noticed. Slight rise in NOx were also observed. 25PSOME yielded better performance, combustion and emission characteristics and proved to be better alternative fuel blend for diesel engine.

Zhang et.al studied performance of diesel-ethyl glycol(DEG) in diesel engine with different energy ratio of EG0,EG5,EG10 and EG15. Port fuel injection (PIT) introduced and direct fuel injecvtion alteration were done. Rise in peak in cylinder pressure and HRR were noted for augumentation of EG ratios and DIT advancing. Increase in EG ratio and advanced DIT, combustion duration increased. BTE improved to 19.45%. Emissions such as HC, CO2,NOx and soot reduced while CO emissions increased. Reduction in PM average diameter was noted. Advanced DIT with suitable EG ratio and proper PIT exhibits better performance and emissions.

Manjunath et.al conducted experiment in diesel engine with dairy scum biodiesel and Bio-CNG. Different blends were analysed and B20 among B10,B20,B30 abd B100 were found to be better blend. Further B20 admitted to different injection pressure and 230 bar found to be better injection pressure. Nozzle hole of 5 holes found to be better among 3, 4 and 5 holes. Finally dual fuelled engine study revealed 29^{o}bTDC injection timing exhibiting improved performance, combustion and emission characteristics compared to other injection timings such as 20, 23,26 and 32^{o}bTDC injection timing.

Xiongho et.al investigated experimentally with single cylinder strategy and double injection strategy in GDI engine with E10 fuel. Effective exponential ratio(EER) and effective experimental efficiency(EEE) and residual gas fraction(RGF) were investigated with both strategy. EER and EEE increased 7.86% and 0.513% peak cylinder pressure(PCP). Maximum heat release rate (HRR) and mean incylinder temperature increased. Double injection strategy proved better result by reducing NOx and HC by 54.46% and 31.81%.

Vinod et.al conducted experiment in CRDI diesel engine ith diesel fuel. Retarding injection timing strategy was adopted and results were compared with previous experimental results. Reduction in NOx and smoke emission were noted. Additionally altering injection pressure were also implemented. This combination led to reduced delay period, improved combustion characteristics and reduced NOx and smoke emission were observed. 500 bar injection pressure and 16^{o}bTDC injection timing combination fetched better result outcome.

Karthick et.al experimented syzgium cumini oil biodiesel as fuel in diesel engine. Different proportions B30,B70,B100 were employed. Single cylinder water cooled, DI diesel compression ignition engine at constant speed operation of 1500rpm with 23^{o}bTDC, 200bar injection pressure was employed. Engine modifications with different injection pressure of 200,220,240 and 260 bar and different injection timing 21,23 and 25^{o}CA bTDC were used. It was found from experiment that 240 bar injection pressure with 25^{o}CA for B30 blend combination gave best result. HC and CO reduce by 46.15% and 15.9%. Smoke reduced to 28.7%. Oxides of nitrogen increased slightly. Thus novel Syzygium cumini oil proved to be promising alternative fuel along with engine modification.

Reddy et.al conducted experiment in single cylinder research diesel engine using 20%mango seed oil methyl ester(MSME20) along with different EGR rates. Injection timing altered with 19^{o}bTDC, 23^{o}bTDC and 25^{o}bTDC. Based on the results it was found that 20% MSME yielded high BTE and improved by 4.54%. Tremendous reduction in emissions such as HC, CO and smoke by 29.26%, 32.43% and 15.38% were obtained for 25^{o}bTDC than 23^{o}bTDC at full load condition. Slight increase in NOx were found which is further reduced by varying EGR rates. Additional 5% EGR to 25^{o}bTDC reduced more NOx by 43.38% without affecting engine performance.

Singh et.al investigated E30 by volume(30% ethanol) and E85(85% ethanol by volume) and E85 (85% ethanol by volume) in gasoline injection engine. Results were compared with E0 ie 100% gasoline. Manifold pressure varied from 800 to 1200mbar. Combined application of ethanol with multiple injection strategy yielded better result such as improvement in brake thermal efficiency. Harmful emission such as HC, CO, NOx, smoke and PM reduced than E0 for E30% blend with altered fuel injection. Multiple injection strategy along with E30 yielded better result comparatively than usual E0 ie gasoline.

Junheng conducted experiment in heavy duty(HD) 6 cylinder turbo cooled diesel engine with diesel/methanol compound combustion(DMCC) mode. Initially CRDI injected and its results were compared. Variable injection timing strategy were employed for present work. Advance injection timing resulted in increases peak cylinder pressure and maximum heat release rate(HRR). BSEC, soot and exhaust temperature decreased with increased in NOx emission. DMCC mode exhibited decrease in HC and CO emissions. Thus advancing injection timing strategy resulted in better resulted output.

However, very rare research has been done on the characterization of Chlorellea Emersonii methyl ester (CEME) biodiesel blend to assess the performance and emission behavior of the CI engine. There is a need for profound studies and ground-level analysis to project Chlorellea Emersonii methyl ester (CEME) biodiesel as a potential fuel source to run the CI engine.

In this study, different injection timings were used to improve engine performance and emission characteristics in a four-stroke diesel engine fueled with Chlorellea Emersonii methyl ester (CEME) biodiesel blend (20 v/v percent), and the results were compared to standard fossil diesel values under the same conditions.

2. Materials and Methods

2.1. Injection Parameters Modification

Fuel injection pressure has great impact on result output. They highly influences atomization, mixing and vaporization of fuel and air mixture thus promoting better combustion. Injection timing alteration is done by adding or removing shims in between fuel pump and injector. Adding 1 shim will increase injection timing of 1^o and removing 1 shim will retard injection timing by 1^o. Thus RT22^{o}bTDC, RT21^{o}bTDC and AT24^{o}bTDC injection timing were obtained.

Fig. 1. Fuel injection parameters modifications.

3. Experimental setup

For present experiment work single cylinder, air cooled, four stroke direct injection stationary research engine was used. Series of instruments is coupled with engine to check fuel performance and other parameters. Test were conducted with electrical eddy current load from 0% to 100% load with 25% increment of loading. For find in cylinder pressure and heat release rate MICO fuel injector with transducer is placed over cylinder head. Exhaust gas analyzer QRO-402 type is used to find amount of HC, CO and NOx level in exhaust gas. Smoke is found usingAVL437C smoke meter. The entire experimental setup is shown in Figure 2. SAE100 lubricating oil is used to reduce friction between moving parts inside engine

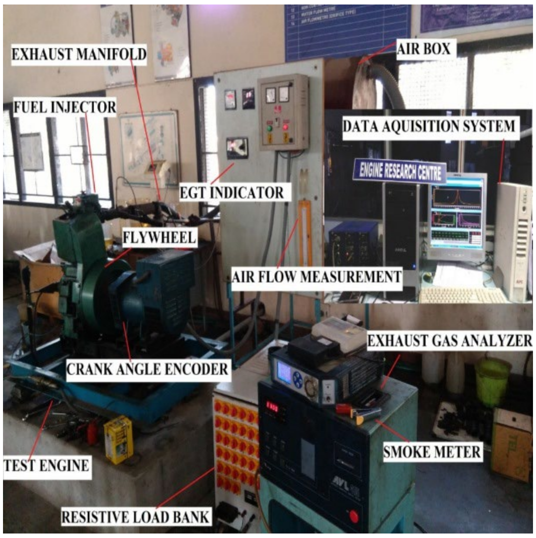

Fig. 2. Layout of experimental setup.

3.1. Comparison with Standard Heat Release Analysis

If standard heat release analysis is performed on the system

$$\breve{Q}LHVdnCxHy + \frac{\breve{C}v}{\bar{R}}Vdp + \frac{\breve{C}p}{\bar{R}}pdV - \delta Q = 0 \quad (5.27)$$

Here, $\breve{Q}LHV$is the lower heating value of the fuel, which is a constant representing how much chemical energy is converted into thermal energy, per mole of fuel. Equation (5.26) can be rewritten as

$$\breve{Q}hrdnCxHy + \frac{\breve{c}v}{\bar{R}}Vdp + \frac{\breve{c}p}{\bar{R}}pdV - \delta Q = 0 \quad (5.28)$$

with $\breve{Q}hr$ is defined as

$$\breve{Q}hr = (-\frac{4}{y-4}\breve{u}CxHy - \frac{4x+y}{y-4}\breve{u}O2 + \frac{4x}{y-4}\breve{u}CO2 + \frac{2y}{y-4}\breve{u}H2O - \breve{c}vT)\frac{dn}{dnCxHy} = \breve{u}CxHy + \frac{4x+y}{4}\breve{u}O2 - x\breve{u}CO2 - \frac{y}{2}\breve{u}H2O + \frac{y-4}{4}\breve{c}v \quad (5.29)$$

It is observed that (5.28) has the same form as (5.29), with $\breve{Q}LHV$replaced by $\breve{Q}hr$.

4. Result and Discussions

From the literature survey it was found that by varying injection parameters droplet size is reduced and surface of fuel droplets burns well. Hence in present work modification in injection timing was adopted such as 24^{o}bTDC(AT24), 22^{o}bTDC(RT22), 21^{o}bTDC(RT21). Engine was tested using these injection timings in modified TRCC combustion geometry with constant quantity of fuel injected at 200 bar standard injection pressure.

Table 1. Annotations for TRCC operated with different injection timing.

Sl. No.	Annotations	Descriptions
1.	D100	100% Diesel fuel
2.	B30	30% Chlorellea emersonii methyl ester(CEME)+70% diesel
3.	BF+HCC	Best fuel(30% Chlorellea emersonii methyl ester(CEME)+70% diesel doped with 10ppm Al_2O_3) operated in hemispherical combustion combustion
4.	BF+TRCC+AT24	Best fuel operated in toroidal re-entrant combustion chamber.
5.	BF+TRCC+RT21	Best fuel operated in toroidal re-entrant combustion chamber.
6.	BF+TRCC+RT22	Best fuel operated in toroidal re-entrant combustion chamber.

4.1. Performance Characteristic

Figure 3 shows variation of brake thermal efficiency of BF operated in TRCC with different injection timing strategy. Maximum value of BTE is reported for BF-TRCC-RT22 at full load than others. Rise in BTE was noted for retarded injection timing of 22°bTDC. On further retarding injection timing of 21°bTDC BTE dropped by 5.26% at 100% load. Due to variation in delay period and air fuel mixture formation in combustion chamber caused better burning of fuel to exhibit improved BTE[111,113,-119]. Improvement in BTE with retarded injection timing strategy was reported by few researchers Reddy et.al, Singh, Marri et.al, Karthic et.al, Duan et.al, Zhang et.al, Kim et.al, Wang et.al and Liu et.al.

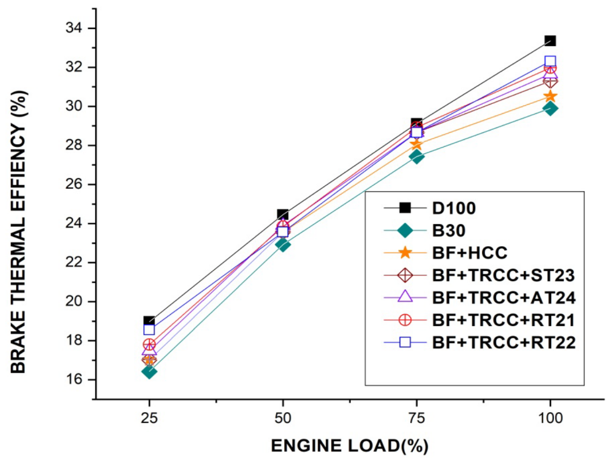

Fig. 3. BTE vs engine load.

Hence retarding strategy benefited in improving BTE. It is clear that standard injection timing of 23°bTDC supported only diesel fuel to exhibit better result but not suitable for oxygenated fuels. Sufficient time available for forming air fuel mixture which supported for effective oxygen utilization and hence improvement in BTE occurred. Similar kind of results obtained form Reddy et.al, Singh, Marri et.al, Karthic et.al, Zhang et.al, Kim et.al, and Liu et.al. Marginal reduction(1.13%) BTE noted for advancing 24°bTDC. Less residence time for AIT fuel reduced cylinder temperature therby inferior combustion is possible. These studies are in par with Channappagoudra et.al and Karthic et.al.

But some researchers such as Reddy et.al, Singh, Marri et.al, Channappagoudra et.al, Karthic et.al, Duan et.al, Zhang et.al, Kim et.al, Wang et.al and Liu et.al. found improvement in BTE. Thus in present study BB+TRCC+RT22 is proved to be best fuel in performance point of view. Several researchers found good result in AIT strategy such as Duan et.al, and RIT strategy fetched good results for Reddy e.al, Singh, Marri et.al, Channappagoudra et.al, Karthic et.al, Duan et.al, Zhang et.al, Kim et.al, Wang et.al and Liu et.al.

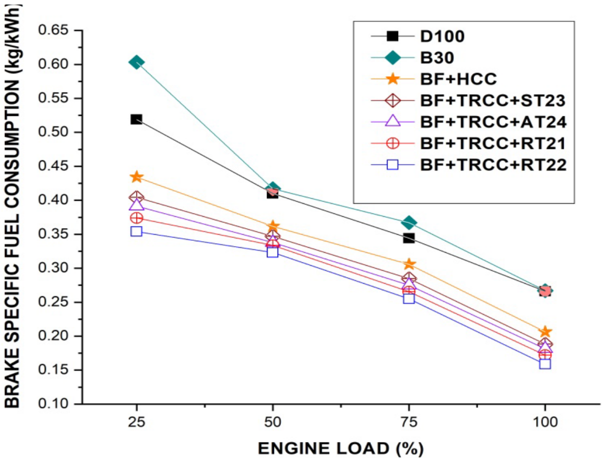

Fig. 4. BSFC vs engine load.

Figure 4 implies the fluctuation of BSFC of fuel with respect to different loads operating in different injection strategy. Highest BSFC is noted for B30 followed by BF-HCC because of inferior mixing and high energy requirement to maintain engine speed constant of 1500rpm. For BF-TRCC-RT22 reduced BSFC is noted indicating effective utilization of fuel in combination with TRCC. Least fuel comsumption of 0.1586kg/kWh is observed for BF-TRCC-RT22. These results were in par with studies of Channappagoudra et.al and Duan et.al, Zhang et.al, thus indicating as optimum fuel injection timing to operate for high combustion efficiency and reducing fuel consumption. It was noted that on further increase of retardation above 21°bTDC(BF-TRCC-RT22) reduction in fuel consumption did not occur instead increased in consuming fuel[45,48,52,90,120]. Same kind of results noted by Reddy et.al, Singh, Marri et.al and Channappagoudra et.al. Improved BSFC was also noted by Karthic et.al, Duan et.al, Zhang et.al, Kim et.al. Few others such as Kim et.al and Wang et.al obtained high BSFC for AIT strategy. Some works such as Reddy et.al, Channappagoudra et.al, Duan et.al, Zhang et.al, Wang et.al and Liu et.al found lower BSFC for advancing injection strategy. Interestingly retarding also increased BSFC for Reddy et.al, Karthic et.al, Duan et.al, Zhang et.al, Wang et.al and Liu et.al.

4.2. Combustion Characteristic

Figure 5 shows variation of incylinder pressure for BF in modified TRCC piston model operated at different injection timing. Conventional BF-HCC model exhibited rise in cylinder pressure of 71bar. Other blends showed improved peak pressure values. Out of which high value is noted for TRCC-RT22 with 82.1bar. This rise in pressure is due to reduction in delay period and improvement in combustion efficiency. Increase in incylinder pressure up to 82.1bar is noted for

TRCC-RT22°bTDC, followed by TRCC-RT21°bTDC and TRCC-AT24°bTDC. Start of fuel injection is lowered for RT22 which enabled more fuel accumulation in cylinder which attributed for more fuel accumulation and sudden releasing of energy from fuel causing increase in peak cylinder pressure[98,102,105,109]. Hence better results were obtained for RIT. These results are analogous with Reddy et.al, Singh, Marri et.al, Channappagoudra et.al, Karthic et.al, Duan et.al, Zhang et.al, Kim et.al, Wang et.al and Liu et.al.

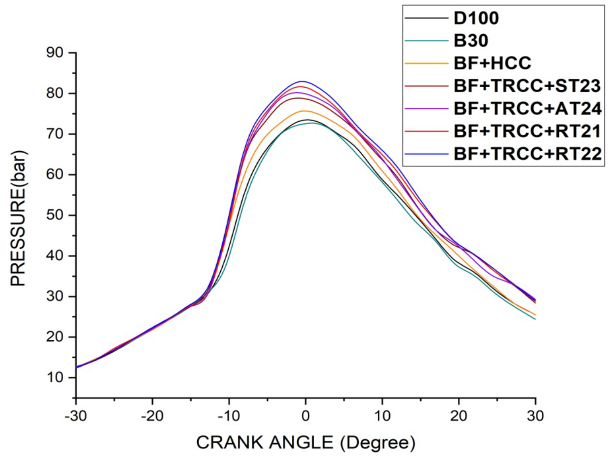

Fig. 5. Pressure vs crank angle.

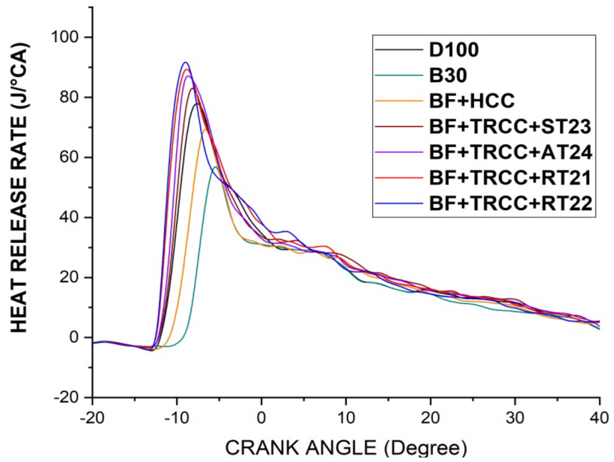

Fig. 6. HRR vs crank angle.

Figure 6 shows the fluctuation of HRR for different injection timing with respect to load to different engine load. Combined effect of nanoparticle with O_2 supply ability and turbulence of modified bowl resulted in improved value of peak HRR. High HRR is noted for TRCC+RT22 followed by TRCC+RT21 and TRCC+AT24 injection timing. Rapid burning of fuel along with catalytic activity of Al_2O_3 also attributed for high HRR for RT22 [101,103,106,109]. Highest HRR of 92.2 J/°CA for RT22 and 82.1J/°CA is observed. These kind of results were also obtained by Reddy et.al, Singh, Marri et.al, Channappagoudra et.al, Karthic et.al, Duan et.al, Zhang et.al, Kim et.al, Wang et.al and Liu et.al.

4.3. Emission Characteristic

Figure 7 shows variation of HC emission with respect to engine load for various injection timing of fuel. BB-TRCC-RT22 possessed lower emission of HC of 0.065g/kWh.0.0525g/kWh and 0.04g/kWh at full load condition. Similar studies were done by Karthic et.al, Duan et.al, Zhang et.al, Kim et.al, Wang et.al and Liu et.al. They were also able to obtained same kind of results. Other injection timing ie AT24 and RT21 exhibited increased HC emission because of lack of residence time for mixture formation and more rich mixture zone formation[120,125,128,130]. Contradictory results were observed by Karthic et.al, Duan et.al and Zhang et.al. Further retardation caused increase in HC emission for Karthic et.al, Wang et.al and Liu et.al. Few studies such as Karthic et.al, Duan et.al and Zhang et.al showed reduced HC for advancing injection timing while Kim et.al, Wang et.al and Liu et.al showed increased HC for AIT strategy.

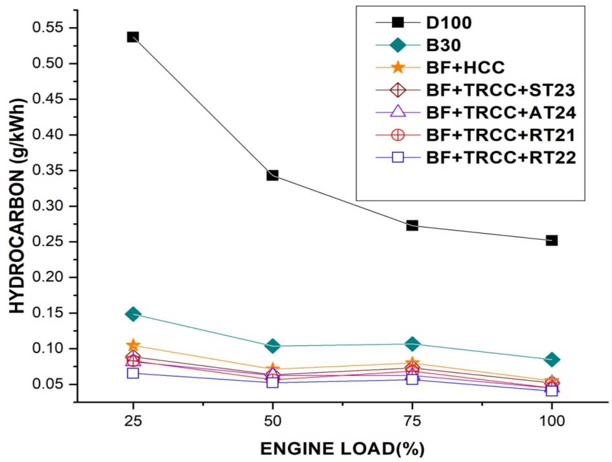

Fig. 7. HC vs engine load.

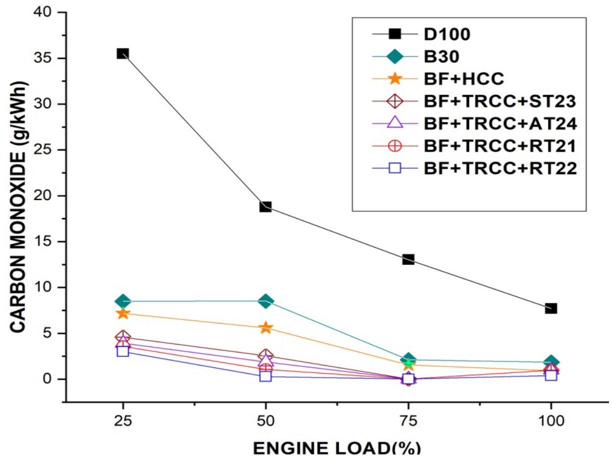

Fig. 8. Carbon monoxide vs engine load.

Figure 8 portrays fluctuation of CO emission of BF operated with TRCC geometry at varying injection timing. From graph it is clear that diesel possessed high CO emission than other oxygenated fuels because of lack of oxygen in fuel which reduced oxidation rate[66,85,115,129]. Along with changed piston geometry and injection timing CO reduced especially for RT22^{o}bTDC injection timing. Reduction in CO when compared to ST23^{o}bTDC was about 42%, 86.7%33.04% and 60.12% respectively. Lower CO for RIT are in accordance with Karthic et.al, Duan et.al, Zhang et.al, Kim et.al, Wang et.al and Liu et.al. Advancing injection timing increased CO by 35.63% and further retarding ie for 21^{o}bTDC also increased CO by 30% because of poor oxidation of CO to CO_2 formation. Thus good atomization, vaporization accelerated better oxidation for RT22^{o}bTDC. Similar results were obtained by Reddy et.al, Karthic et.al, Duan et.al, Zhang et.al, Wang et.al and Liu et.al.

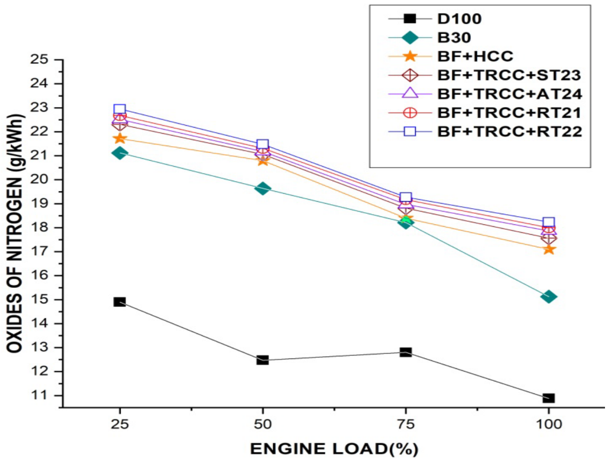

Fig. 9. Oxides of Nitrogen vs engine load.

Figure 9 illustrates oxides of nitrogen formation with respect to engine load for varying injection timing. NOx emission is high for RT21 and RT22about 5.06% and 6.25% higher at higher load than diesel. Improvement in fuel residence time for accumulation along with high adiabatic flow temperature caused higher NOx formation. Moreover excess O_2 and good combustion made O_2 and N_2 to oxidize to form NOx emission[90,115,120,135]. Thus retarding injection timing of 22^{o}bTDC the oxides of nitrogen reduced. Similar results were obtained by Reddy et.al, Singh et.al and Marri et.al, Advancing strategy decreased NOx emission which is in line with Wang et.al and Liu et.al. Few researchers such as Reddy et.al and Karthic et.al obtained high NOx formation for AIT. Increase in NOx with RIT is observed by Channappagoudra et.al, Karthic et.al, Duan et.al, Zhang et.al and Kim et.al, Wang et.al and Liu et.al.

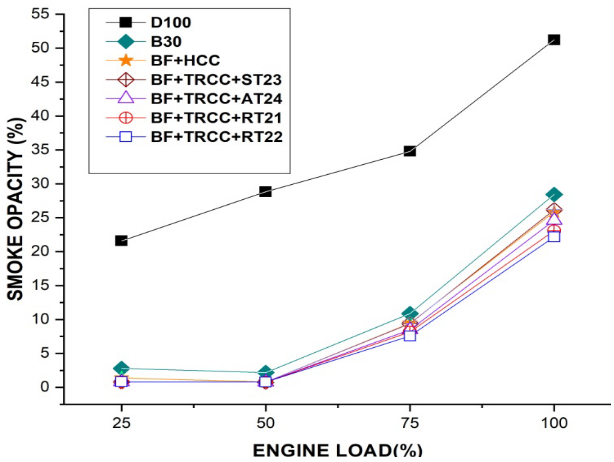

Fig. 10. Smoke vs engine load.

Figure 10 depicts the smoke formation of BF with respect to engine loas with different injection strategy. NOx-smoke trade of characteristics are in par with each other. BF-TRCC-RT22 exhibited 0.78, 0.76, 7.15 and 23.21% at 25%,50%,75% and 100% engine load. This can be due to high residence time for fuel to accumulate enabling high incylinder pressure and heat release rate along with good spray characteristics and less rich fuel zone these aspects caused reduced smoke emission for RT22^{o}bTDC[118,121,135,140]. These results are inpar with Reddy et.al, Singh, Marri et.al, Channappagoudra et.al, Karthic et.al and Duan et.al, Advanced strategy increased smoke due to less residence time and large fuel size owing to more rich zone formation. Few studies such as Zhang et.al, Kim et.al, Wang et.al and Liu et.al. obtained high smoke for AIT strategy.

5. Conclusion

Performance of RT22^{o}bTDC was better with improvement in BTE and reduced BSFC because of proper time for residence of fuel which led to high combustion efficiency and improvement in performance. CO emission reduced by 60.2%, HC emission by 18.8%, NOx increased by 6.25% and smoke lessened by 22.17% is obtained because of high swirl and tumble motion, good oxidation and more residence time owing to good combustion. High in cylinder pressure and HRR of 82.91 bar and 93 J/^{o}CA were obtained because of good spray characteristics and good combustion quality. Thus overall B3O+TRCC+RT22 exhibited good performance, combustion and reduced emission.

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