Journal of Harbin Engineering University Vol 44 No. 11
ISSN: 1006-7043 November 2023

An Experimental Investigation on CI Engine Powered with Biodiesel of Used Temple Oil at different Injection Pressures and Combustion Chamber Shapes

Sardar M. Shaikh[1*], S. V. Khandal[2]
[1, 2]Department of Mechanical Engineering, Sanjay Ghodawat University, Kolhapur-416118, Maharashtra, India.

Abstract
The aim of this research work is to study effect of injection pressure (IP) on the performance of compression ignition (CI) engine. In India, there is a huge potential of Used Temple Oil (UTO) due to many mythological and religious beliefs and it can be used to produce biodiesel. Experiments were performed on CI engine powered with diesel and biodiesel by changing IP and combustion chamber shapes at different loads. In the first part, IP varied in steps of 20 bar and in the second part, combustion chamber shape [hemispherical combustion chamber (HCC), toriodal combustion chamber (TCC) and toriodal re-entrant combustion chamber (TRCC)] changed keeping the optimized IP which provides better engine performance. The output characteristics of the engine were reported and analyzed. It has been observed that the increase in IP gave better results in terms of performance parameters, the better results were obtained at an IP of 200 bar and the emissions like smoke, Hydrocarbon (HC) and Carbon monoxide (CO) are comparatively lower for biodiesel as compared with diesel fuel. However, NOx was higher than that of the diesel fuel. Also it is revealed from this work that TRCC yielded better results as compared with other CC shapes.
Keywords: Used Temple Oil (UTO); Biodiesel of Used Temple Oil (BTO); Injection pressure (IP); Combustion Chamber Shapes; Performance

1. Introduction

In the world, India is second populous, fourth most green house gas emitter and fifth largest energy consumer country. Development of nation leads to the requirement of energy. Using hydrocarbons fuels all automotive and transportation vehicles are powered by internal combustion. In natural resource management sustainability, is a key principle and all of which are interdependent in terms of operational efficiency, lower impact on environment and point of view of socio economic consideration. Depleting world reserves and its use result in green house gas emission made fossil fuel energy resources unsustainable [1].

Today's world much more depends upon petroleum products for transportation and to run agriculture mechanical devices. On account of supreme fuel efficiency diesel engine dominate the transportation and agriculture machinery field. The diesel fuel consumption is very high in India comparing to petrol consumption, 30% and 70% of the petrol and diesel consumption is estimated. Air pollution is the major contribution of diesel engine which leads ozone and smog and increases the toxic air contaminants. Thus there is lot of pressure on researchers to reduce emission, as CO entering in the blood stream lead to hypoxia and if inhaled lead to other health problems. Therefore the world's attention turned towards biomass based fuels which are easily available from renewable sources [2].The new policy of bio fuel promotes the usage of waste lands for generation of feedstock; the policy will also encourages taluks and gram panchayats, the local administrative bodies to plant non-edible oilseed bearing trees and crops like Meliaazadirachta, Pongamia, pinnata, Castor, Jatropha carcus, Callophylluminnophylum, Simaroubaglauca and Hibiscucescannabbinus for production of biodiesel. Jatropha curcas is identified by the National Biodiesel Mission (NBM) in 2017 as the most suitable non edible oil seed to blend with diesel by 20% [3].

For making diversified products like vermicomposting, biogas, dyes, incense sticks, concrete aggregate replacement temple waste can be utilized and can be disposed safely in an environmental with care. Waste management is the main motto of this study, because it would be used as a resource that would be recycled and generate additional revenue. To live in a cleaner and a healthier surrounding floral waste use benefit the society. The waste management in sustainable way for Temples with the concept of green temple would help the Governments [4-5].Tapanee Hongratanaworakit et al. [6] has investigatedthe blended oil simulating effect demonstrates in investigation. Drastic increases in systolic blood pressures, diastolic blood pressure, mean arterial blood pressure were shown by the blended oil and an increase of autonomic arousal pulse rate was indicated. At the behavioral level inhalation of the oil lead to activation, i.e., more alert subjects feed, more vigorous cheerfulness than before the oil administration. In self-evaluation terms this finding points in increase of arousal, by the stimulating or activating effects concept the effects of blended oil may be characterized by inhalation. Pani Sharanappa et al. [7] have presented the ternary fuel blends brake thermal efficiency (BTE) is a little less than the neat diesel. The B30 blend of ternary fuel has yielded 27% BTE. It increases in injection pressure. The ternary fuel blends brake specific fuel consumption (BSFC) is greater than the neat diesel. With increase in injector opening pressure (IP), BSFC reduces, for B30 the lowest BSFC is 0.3 Kg / kW-hr. The exhaust gas temperature (EGT) has lowest for B20 blend fuel, it is having 450^0C and 430^0C at 180 and 220 bar pressure correspondingly, with increase in IP the EGT reduces. As IP increases the peak cylinder pressure (PP) reduces. The PP is greater for pure Mahua biodiesel as compare to diesel. Sirivella Vijaya Bhaskar et al. [8] have described; one of the significant engine parameters that affect the performance of diesel engine characteristics is the IP. The test is conducted on 4 strokes, single cylinder and water cooled diesel engine fueled with Jatropacurcas biodiesel with different blends at different IPs from 200 to 240 bar. In this test the highest BTE, lowest EGT and BSFC biodiesel obtained for B20 blend compared with all other biodiesel blends. At 220 bar IP the engine performance characteristics are optimum. This result also shows that with the increase of biodiesel percentage, the BSFC and EGT are increasing but the BTE has decreased. Suchith Kumar M.T.et al. [9] has investigated, by transesterification process Calophylum Inophyllum biodiesel obtained and it is used to conduct performance test on compression ignition engine at different IP, B20 biodiesel blend at 150 bar pressure maximum BTE and minimum BSFC is obtained. The B20 blend and 150 bar IP concluded as optimum values. S. Mahalingam et al. [10] in their study, the Jatropha and rubber seed oil biodiesel are carried to conduct the experimental investigation. The Oxides of Nitrogen (NOx) is increased when the IP reduced, but NOx value was reduced when IP from 210 to 220 bar, by further increase in IP (220bar) the NOx value was less amount compared to 210 bar pressure. The NOx value is again reduced when IP is increasing to 240bar. When compared to the different IP and biodiesel blend proportions B20 blend at 240bar, very less NOx emission was obtained, which gives good performance. K. M. Mriyunjaya Swamy et al. [11] has carried out; Algae biodiesel was used to evaluate the diesel engine performance and emissions. Higher pressure, decreases fuel droplet size and lead to fine fuel spray, therefore the performance and emission at 220 bar IP is inferior to the IP 200 bar. At 30^0 before top dead center the engine performance and emission parameter significantly improved.

The effect of both IP and Combustion Chamber (CC) shape on the performance of Biodiesel of Pongamia oil run CI engine with toriodal re-entrant combustion chamber (TRCC) yielded higher BTE besides better BSFC. The trend could be because of higher IP and better air motion led to enhance burning of the air-fuel mixture [12]. The effect of CC shapes & injection strategies on the performance of Uppage oil methyl ester (UOME) powered CI engine was studied and results showed that toriodal CC (TCC) yielded better engine output [13]. The experimental investigation on CI engine powered with HOME and producer gas showed 4–5% higher BTE and reduced emission levels when re-entrant type CC and IP of 230 bar [14].

2. Materials and Methods

2.1 Fuel used in the current work

The UTO is considered as first generation biofuel (mixture of vegetable oil) and also second generation biofuel (waste oil if it is excess). From Shri Sayambhu Hanuman Mandir, UTO was collected. Table 1 shows the UTO collection per annum from only two temples, it is possible to collect huge amount of UTO from many temples which are registered under Government of Maharashtra.

Table 1: Oil Collection per Annum at Temples

Name of the Temple	Year	Quantity oil collected in Kg/Year
Shri Sayambhu Hanuman Mandir (Temple) Dongarwadi,Taluka-Walva, Dist- Sangli	2021-22	3235
	2022-23	3910
Shree Balu mama Mandir (Temple), Admapur, Taluk - Bhudargad, Dist - Kolhapur	2021-22	6120
	2022-23	6574

2.2 Properties of Used Temple Oil

The fuel properties of UTO and Biodiesel Used Temple Oil (BTO) were determined as per the standard prescribed methods. Table 2 shows properties of biodiesel as per ASTM, diesel [15], UTO and BTO.

Table 2: Properties of UTO and BTO

Property	Unit	ASTM D6751	Diesel	UTO	BTO
Kinematic viscosity at 40^0C	mm^2/s	1.9-6.0	2.58	26.6	5.1
Density, at 15^0C	kg/m^3	870-890	831	910	870
Flash Point	^{0}C	130 (min)	50	202	164
Calorific value	KJ/kg	37,500	42,500	38,682	39,080

2.3 Experimental setup

In order to get the required performance, the experimental work requires an engine test setup which is suitably instrumented. Under variable injection pressure (IP) at 180, 200 and 220 bar the experimental setup consists of a Kirloskar AV1 single cylinder, 4-stroke CI engine of 3.75 kW at 1500 rpm and a compression ratio of 17:1. The engine was coupled with an eddy current dynamometer. Figure 1 shows experimental setup of CI engine test rig. Different CC shapes used is provided in Fig. 2 to Fig. 4.

]

Fig. 1: Experimental setup of Diesel engine test rig

Fig. 2: Hemispherical CC

Fig. 3: Toriodal CC

Fig. 4: Toriodal re-entrant CC

2.4 Uncertainty analysis

Table 2. Measurement accuracy and calculated parameters variation

Parameter Measured	Accuracy (±)
Load, N	0.1
Engine speed, rpm	2
Temperature, °C	2
Parameter Measured	**Uncertainty (%)**
Smoke	±1.4
HC	±1.4
CO	±2.2
NOx	± 6
Parameters Calculated	**Uncertainty (%)**
BTE, (%)	±1.2

HRR per CA was tabulated with first law analysis for 100 cycles. An AD-converter gave sensor signals, indicating pressure and TDC position. Table 2, depicts accuracy and variation in calculated parameter.

3. Results and Discussions

In section 3.1 the effect of IP on performance of diesel engine discussed and in section 3.2 the effect of combustion chamber shape discussed. During the experimentation fuel injection time was kept constant at 23° bTDC.

3.1 Effect of IP on performance

During the experimentation HCC shape was used.

Brake Thermal Efficiency (BTE)

Figure 5 shows that the BTE is lower for BTO at low IP considered i.e., 180 bar. When the IP increased to 200 bar, the BTE of BTO fuel has improved substantially. This may be because of better combustion, improved atomization and reduction in the viscosity [16]. It is also reported that, the BTE is decreased when the IP further increased to 220 bar. At higher IP the size of the fuel droplets decreases and very fine fuel spray results in, because of this, penetration of the fuel spray reduces with momentum of the fuel droplets reduction. It is noted that the BTE is highest for BTO at 200 bar IP. It could be observed that variation of BTE at loads was better at IP of 200 bar

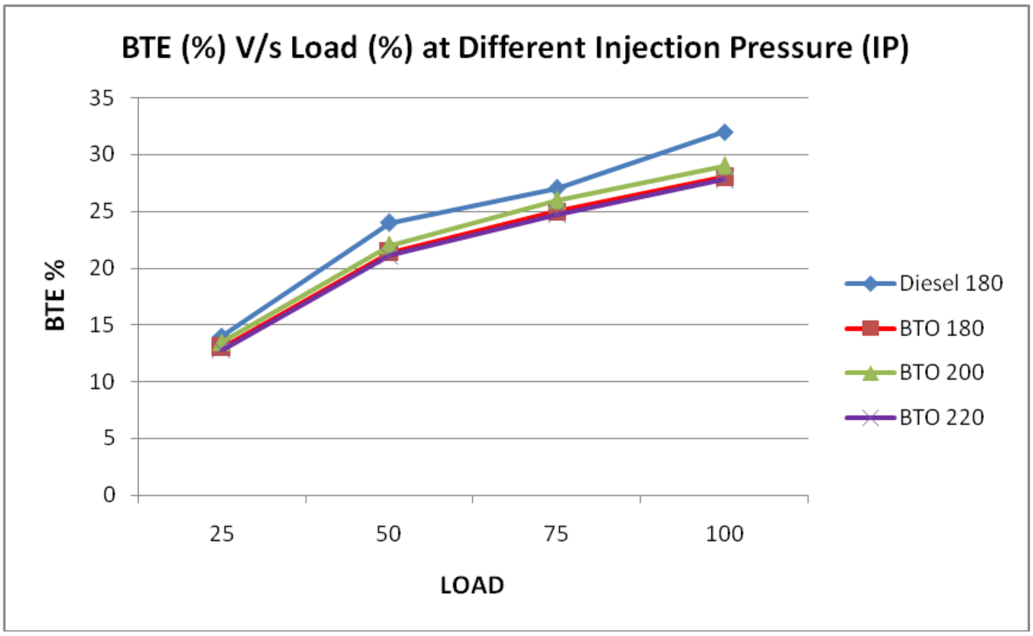

Fig. 5: Variation in BTE at different engine load and different IP

Brake Specific Fuel Consumption (BSFC)

From Fig. 6, it is observed that BSFC is decreasing with an increase in IP. At fuel IP of 200 bar, the BSFC for BTO is slightly higher than the conventional fuel at lower loads, because lower calorific value of biodiesel, BSFC decreases with increase in IP up to 200 bar, beyond this the BSFC decreases

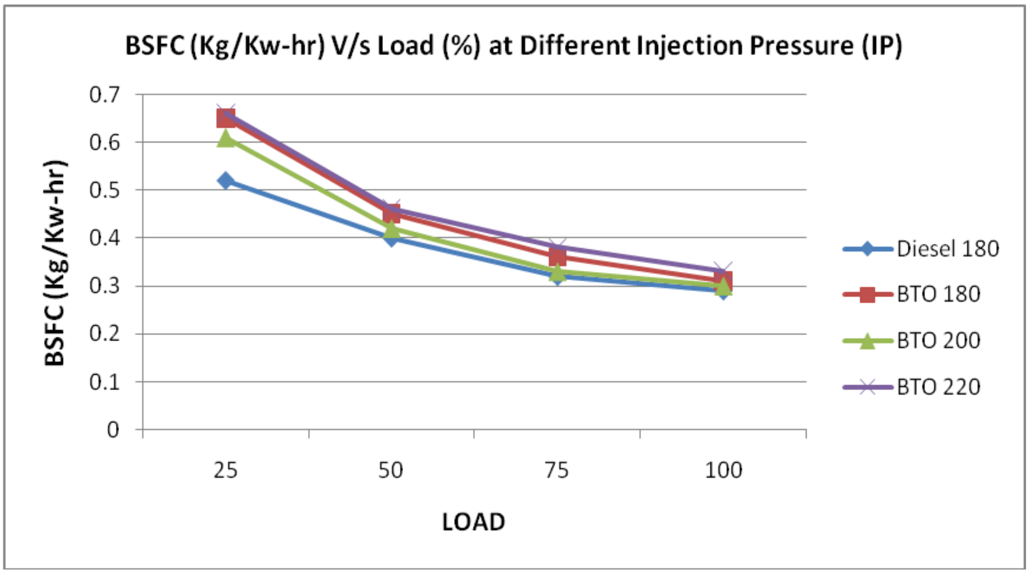

Fig. 6: Variation in BSFC at different engine load and different IP

Carbon Monoxide emission

Figure 7 shows the difference of CO emissions of BTO run engine, with load at three IP at varied load in comparison to 180 bar diesel operation. The CO emission of BTO at different fuel IP were comparatively lower than conventional diesel fuel at all loads. This is attributed to the presence of more oxygen in biodiesel, which helps the combustion to take place better. Figure 7 shows at 200 bar, marginal decrease in CO emission as compare to other pressures. At this pressure atomization of fuel greatly improved and support the combustion process.

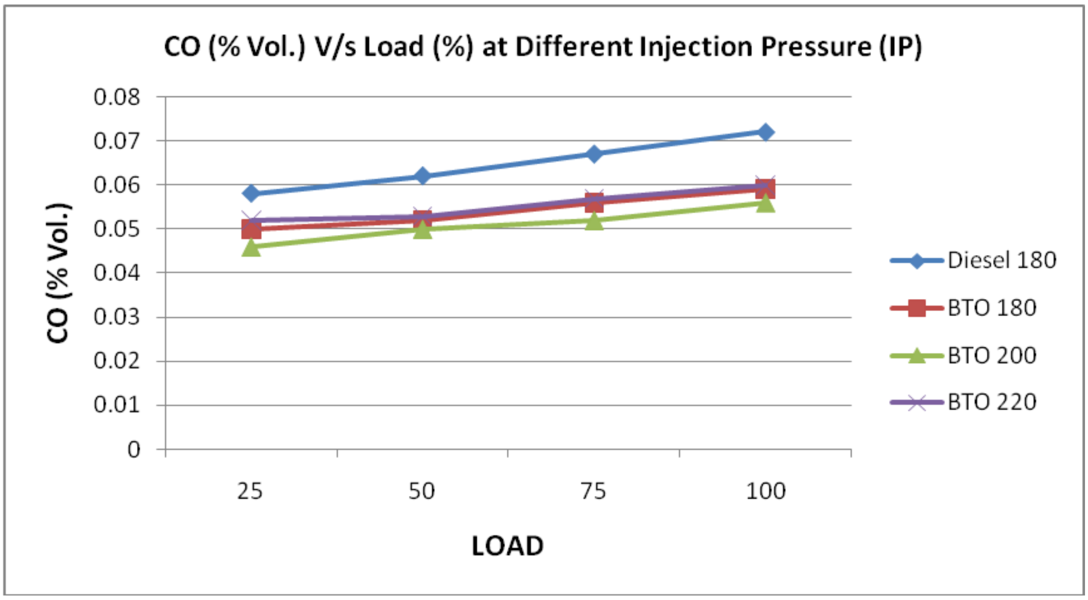

Fig. 7: Variation in CO at different engine load and different IP

Hydro Carbon (HC) emission

Figure 8 depicts the results of HC emission of BTO powered diesel engine at different IP. When there is an increase in IP from 180 to 200 bar decrease in HC emissions was reported. But HC emission was little higher at 220 bar. This is due to partial combustion of fuel on account of finer fuel spray which reduces the momentum of fuel droplet. Lowest value of HC emission reported with IP of 200 bar

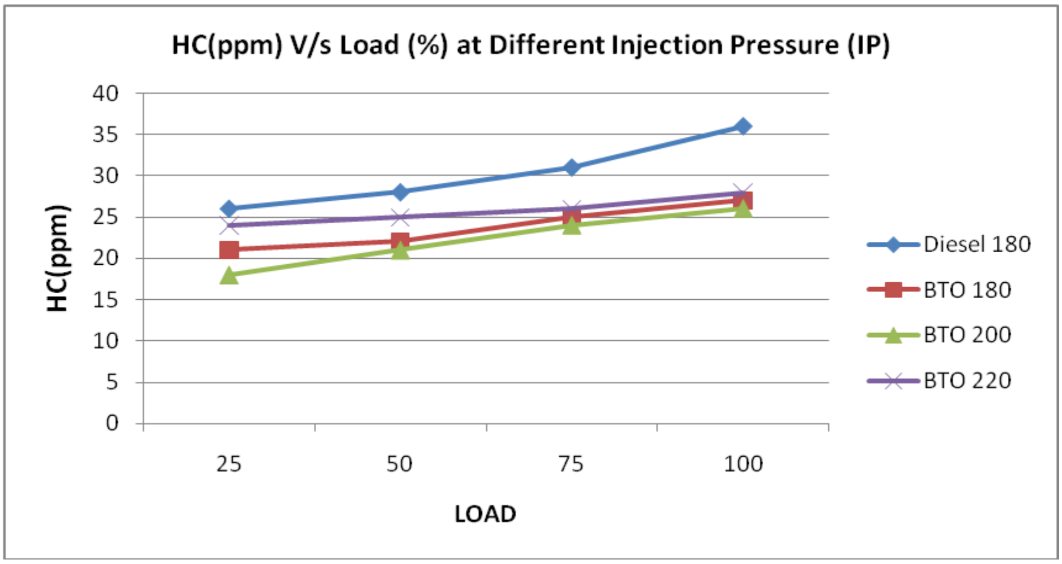

Fig. 8: Variation in HC at different engine load and different IP

Oxides of Nitrogen (NOx) Emission

Figure 9 shows the NOx variation at BTO blend at full load condition. At 200 bar NOx observed to be lower. Due to decreased engine EGT, a lower NOx emission at this IP may occur. Higher NOx emissions at 180 and 220 bar IPs result from higher exhaust temperatures. It also shows the NOx emission variation with load at optimal 200 bar IP for BTO.

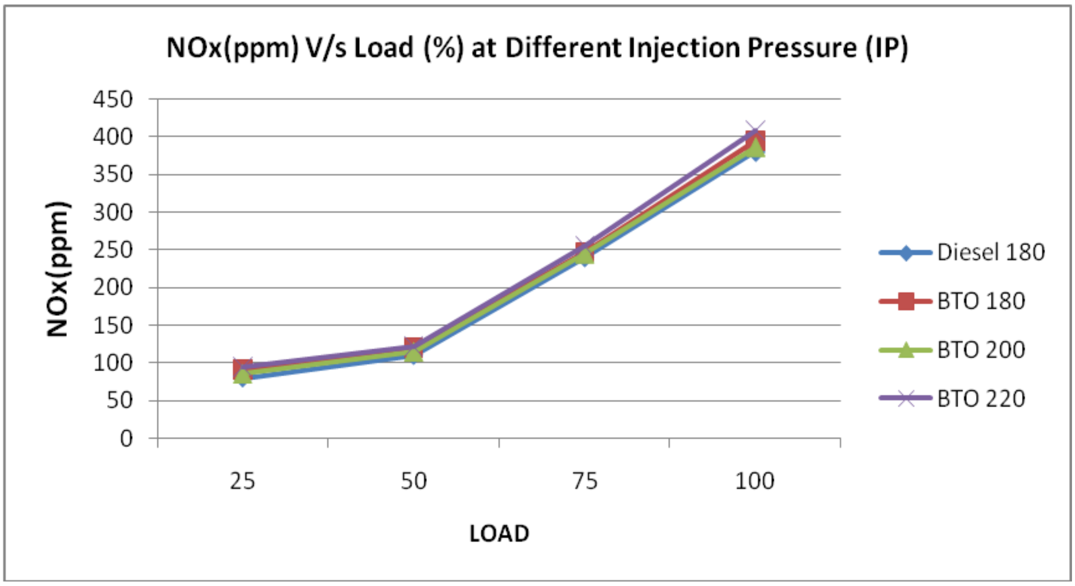

Fig. 9: Variation in NOx at different engine load and different IP

Smoke Opacity

Variation in smoke resulted by diesel engine run on BTO at different IP and load is given in Fig. 10. It is seen that the smoke for BTO fuel has decreased with increased IP from 180 to 200 bar at full load. In addition, the higher opacity was recorded at 220 bar pressure. The BTO fuel is slightly below the base level of opacity of diesel fuel operation, mainly due to the no sulphur and the existence of oxygen in biodiesel, which is essential for better fuel combustion

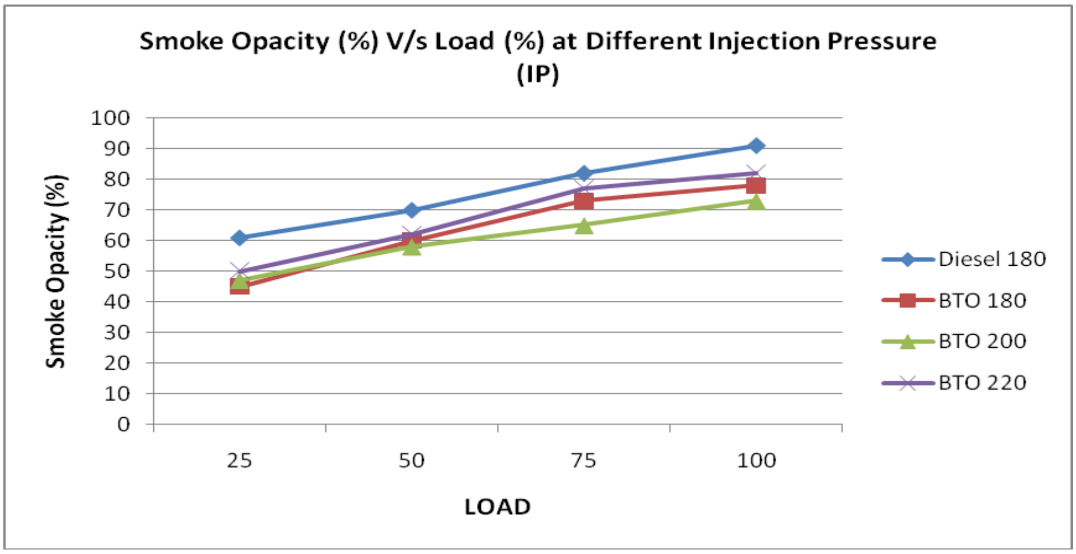

Fig. 10: Variation in Smoke at different engine load and different IP

3.1 Effect of Combustion Chamber shape on performance

During the experimentation different CC shapes were used viz., HCC, TCC and TRCC. Fuel IP was 200 bar.

Brake Thermal Efficiency (BTE)

Figure 11 illustrates the variation in BTE with BTO run CI engine with different CC shapes and load. The BTE for BTO operation were lower than neat diesel operation for all loads due to its higher viscosity lower energy content and volatility. The mixture formed was poor that led to incomplete combustion and hence lower BTE with BTO. BTO powered engine operation with TRCC showed enhanced results as compared to other CC selected. TRCC prevents the flame front propagation from travelling in squish to form better mixture, due to better air motion, increasing swirl and tumble flow that lowers exhaust soot. BTE was higher for TRCC shape as it direct the flow field inside the cylinder sub volumes.

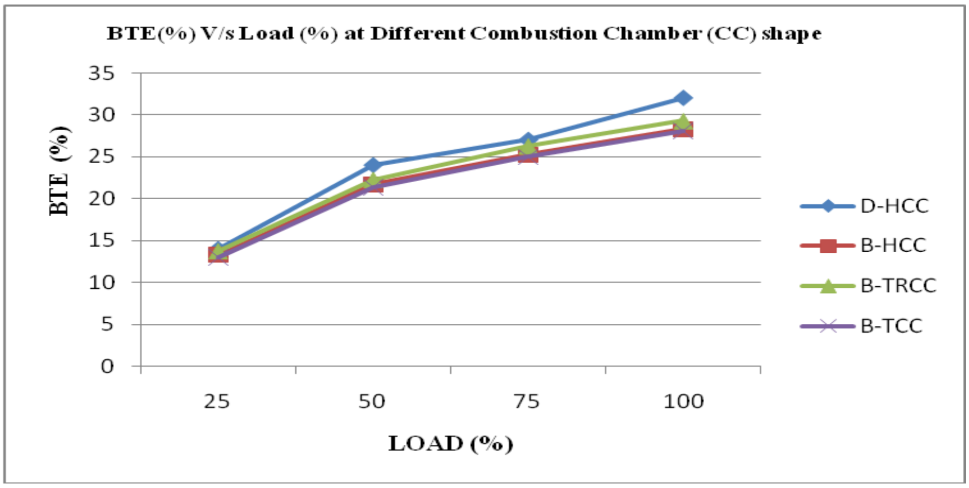

Fig. 11: Variation in BTE at different engine load with different CC shapes

. **Brake Specific Fuel Consumption (BSFC)**

From the Fig. 12 it could be seen that the BSFC is decreasing with an increase in IP for BTO. At optimum IP i.e., 200 bar the BSFC for BTO is slightly higher than the conventional fuel at lower loads, because lower calorific value of biodiesel, BSFC decreases with IP increase up to 200 bar, beyond this value BSFC decreases. For 200 bar IP the BSFC is lower for BTO.

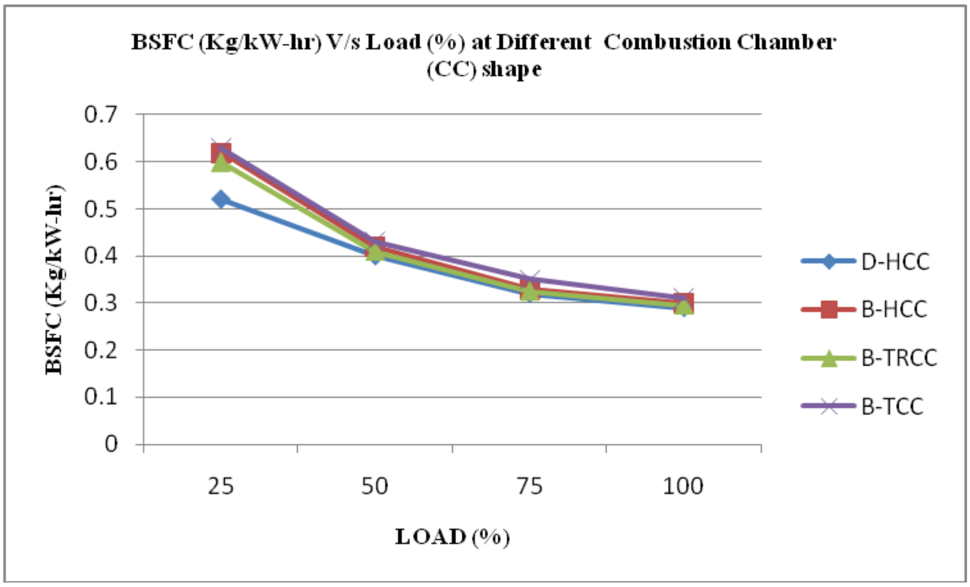

Fig. 12: Variation in BSFC at different engine load with different CC shapes

CO and HC emission

Figures 13 and 14provide the variation in the HC and CO of the engine powered with the diesel and BTO for all loads. Both CO and HC were lower for BTO as compared to mineral diesel. Lower BTE of BTO on account of incomplete combustion might be the reason for this trend. However, TRCC engine yielded reduced HC and CO as compared to same obtained with other CCs. Higher turbulence motion in the TRCC gave lower heat losses besides enhanced oxidation that reduced these emission.

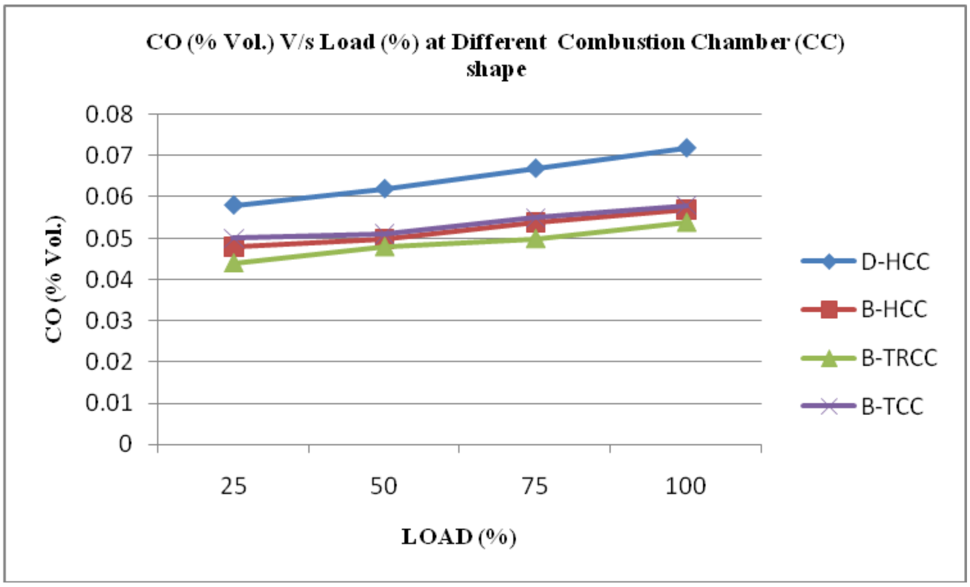

Fig. 13: Variation in CO at different engine load with different CC shapes

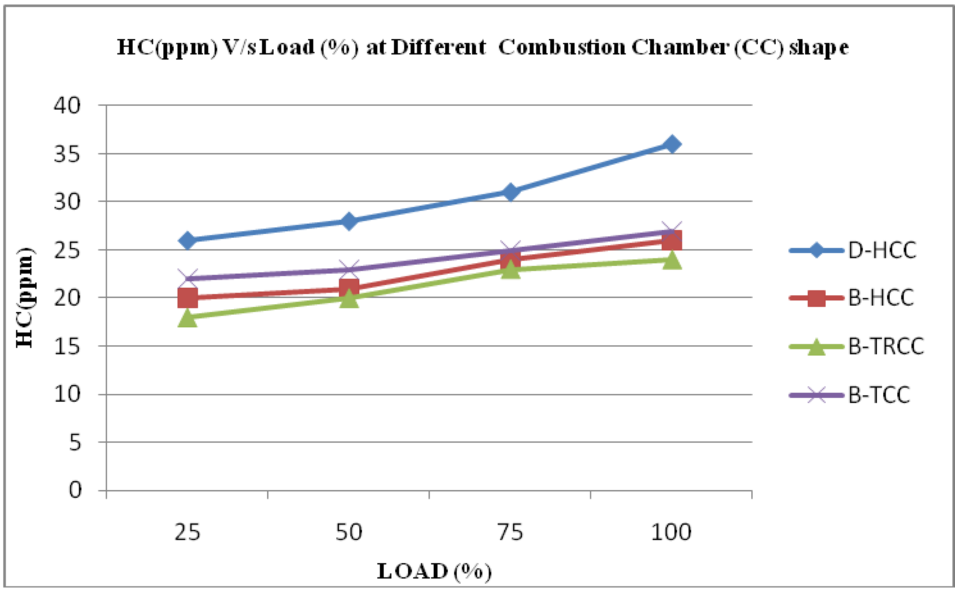

Fig. 14: Variation in HC at different engine load with different CC shapes

Oxides of Nitrogen (NOx) Emission

NO_x were higher for diesel in comparison with BTO which could be evidenced from Fig. 15. For this trend, the higher HRR along with elevated temperature during premixed phase of combustion could be responsible. Presence of oxygen in the BTO might also contribute to higher NOx emission. Slightly higher NO_x were reported with TRCC but lower with other CC shapes employed. The probable reason for this might be better combustion as more homogeneous mixing happened due to turbulence.

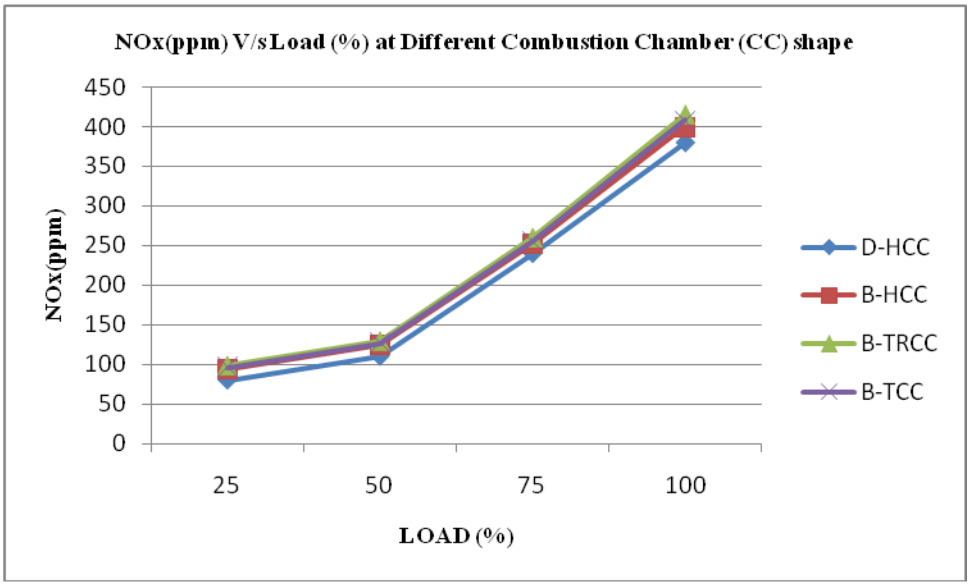

Fig. 15: Variation in NOx at different engine load with different CC shapes

Smoke Opacity

Figure 16 depicts change in smoke level of engine run with BTO with different CC shapes and load. Smoke emission for mineral diesel was lower than BTO. Complete combustion on account of proper fuel-air mixing could be the reason for the trend. However, TRCC showed lower smoke as compared to other CC shapes. Better air-fuel mixing due to higher turbulence led to better combustion that reduced the smoke in TRCC.

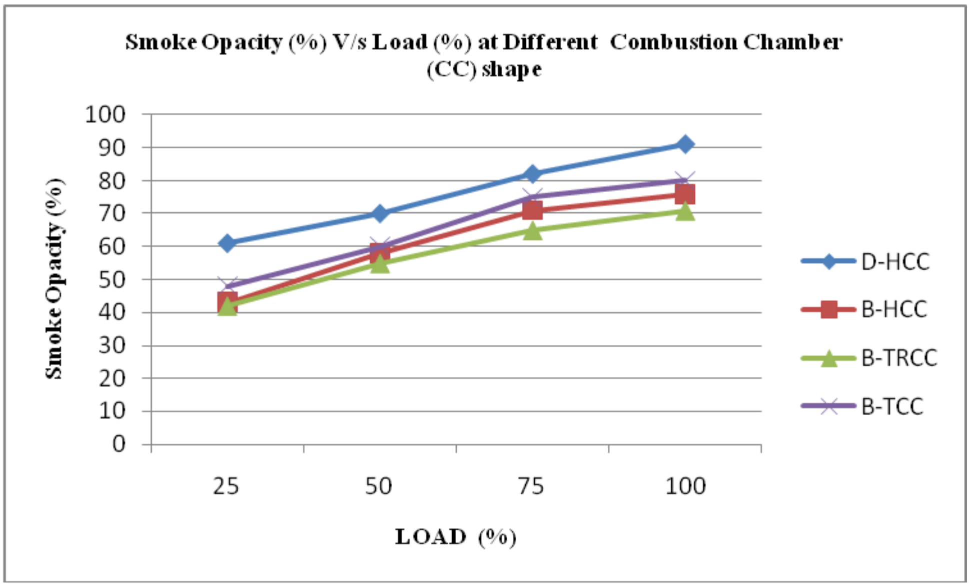

Fig. 16: Variation in Smoke at different engine load with different CC shapes

Combustion characteristics

Combustion characteristics like ignition delay (ID), combustion duration (CD), peak pressure (PP) and heat release rate (HRR) is given in Fig. 17 to Fig. 20. From these Figures, ID found decreasing with load where as CD, PP and HRR increasing with load. However TRCC showed better results as compared with other CC used in the work due to better combustion on account of swirl led homogeneous mixture.

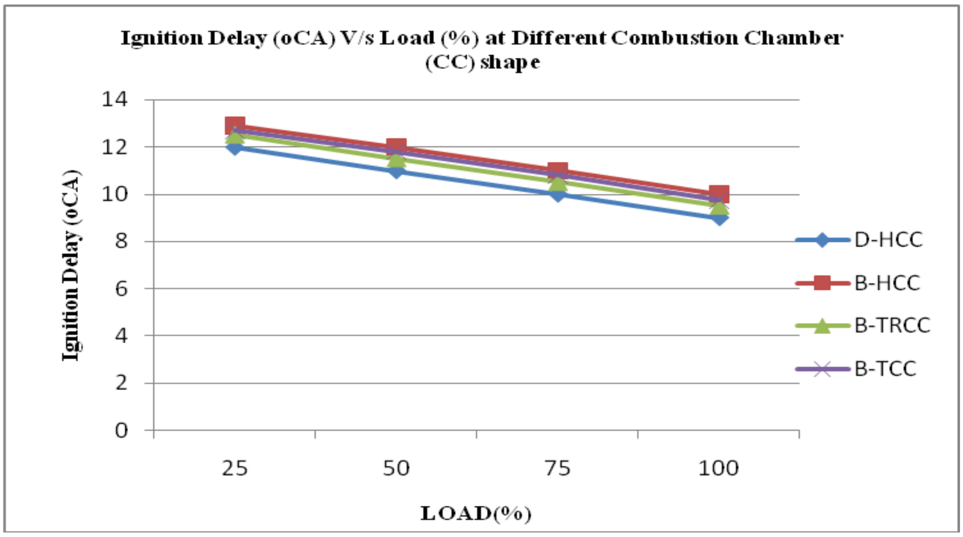

Fig. 17: Variation in ID at different engine load with different CC shapes

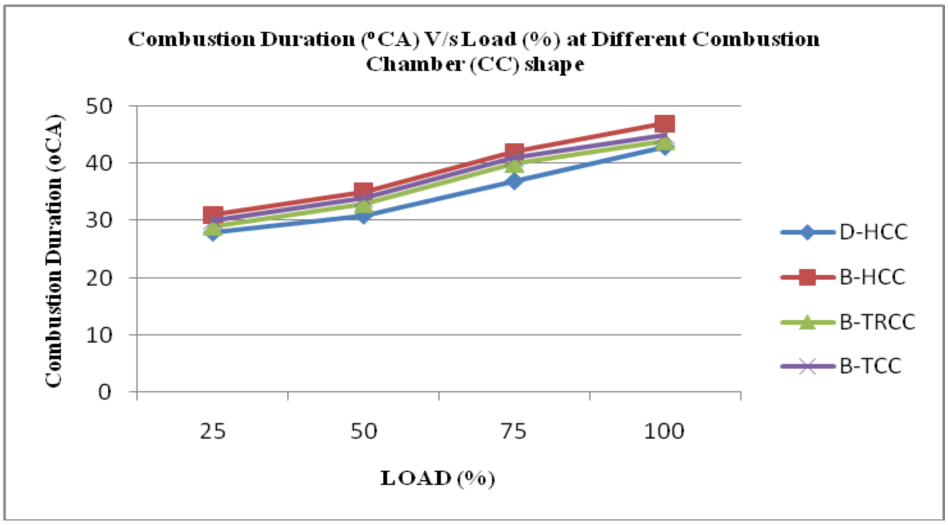

Fig. 18: Variation in CD at different engine load with different CC shapes

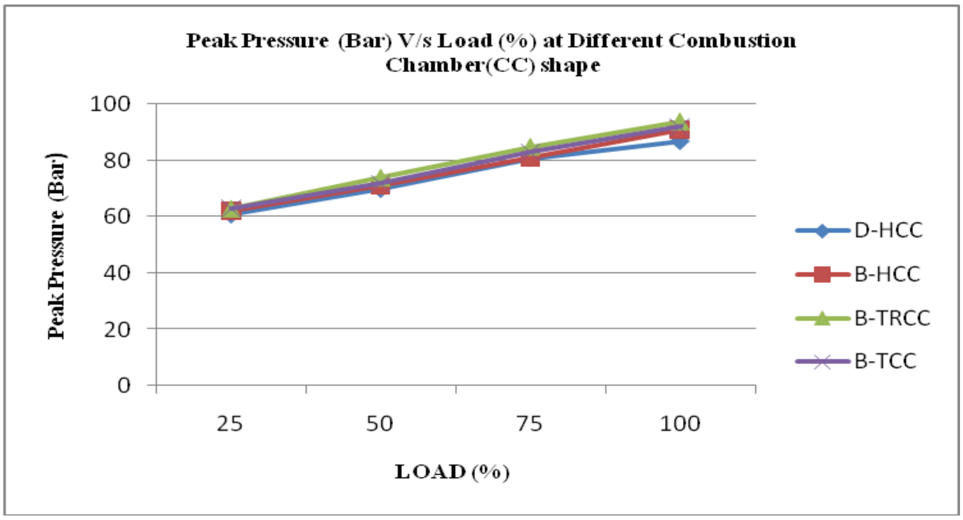

Fig. 19: Variation in PP at different engine load with different CC shapes

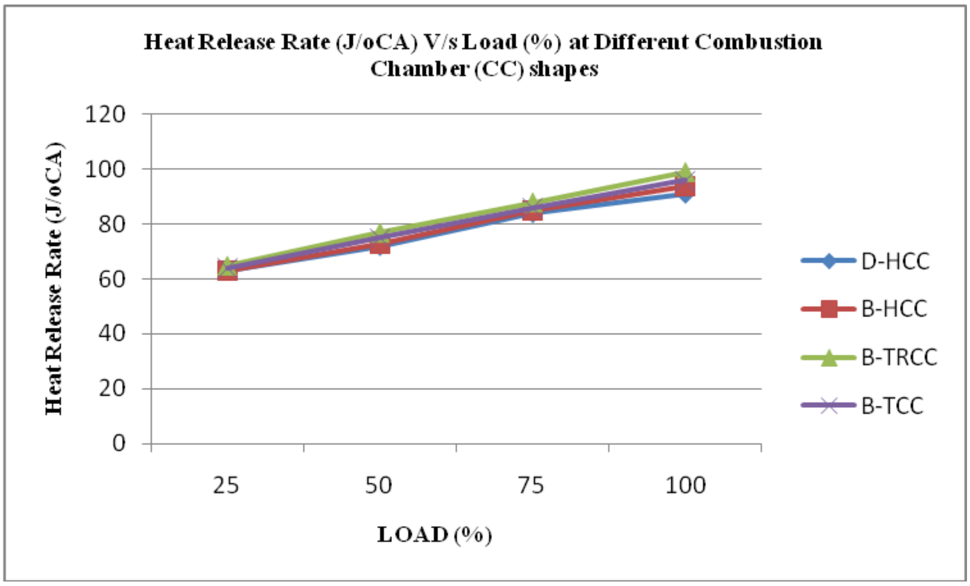

Fig. 20: Variation in HRR at different engine load with different CC shapes

Conclusions

The study has been carried out as a function of performance, exhaust emissions and combustion parameters at different loads and IP. The engine performance and emission characteristics are measured and analyzed. From the present work the following conclusions could be drawn:

- A successful and stable operation of diesel engine was possible with BTO with conventional diesel with different IP without any modification in the hardware.
- A major source of UTO is Indian temples, where people pour oil over the idols, due to various mythological and religious beliefs. This mass collection of oil cannot be reused and is a waste. Therefore this oil is potential substitute for diesel and ensures energy security and improves the national economy.
- The major properties of biodiesel evaluated according to ASTM standard and they are compatible with diesel fuel.
- An IP of 200 bar resulted in better spray characteristics, better fuel atomization and hence the better performance and lower emissions.
- TRCC shape yielded better results as compared with other CC shapes used in the study due to better mixture formation and combustion.

Overall it could be concluded from the current experimental work that diesel engine could run on BTO yielding a similar performance as that of diesel at 200 bar IP with TRCC shape.

References

1. R J Crooks Comparative bio-fuel performance in I C Engine, Biomass and Bio-energy 2006; 30: 461-468
2. S. P. Chincholkar, Saurabh Srivastava, A. Rehman, Savita Dixit and Atul Lanjewar. Biodiesel as an Alternative Fuel for Pollution Control in Diesel Engine, Asian J. Exp. Sci., 2005,19 (2), 13-22.
3. GAIN Report number IN8085, India bio fuels annual 2018 date 9/28/2018, 1-26
4. Ishayadav, Shelja K. Juneja and Sunita Chauhan "Temple Waste Utilization and Management: A Review "International Journal of Engineering Technology Science and Research, Vol-2, (2015) pp 14-19
5. Priyanka Tiwari, Shelja K Juneja, " Management of Floral waste generated from temples of Jaipur city through vermicomposting " International Journal of Environment, Vol-5 (1), 2016, pp-1-13
6. Tapanee Hongratanaworakit, Pongpat Srimuang, Ampot Wichapreechar, Tharada Akarapattaranithi, benjaporn Taorang, Pimtidarawdlaurh" Chemical Composition and Effects of Blended Essential oil on Humans" Journal of Applied

Pharamaceutical Science, Vol-7 (01), 2017, pp-165-170
7. Pani Sharanappa, mallinath C. Navindagi. Investigation of performance and Combustion Characteristics of DI Diesel Engine Fuelled with Ternary Fuel Blend at Different Injection Pressure. World Journal of engineering and Technology.2017; 5: 125-138
8. Sirivella Vijaya Bhaskar, G. Satish babu. Effect of Injection Pressure on Performance of CIDI Engine Fulled with Jatropha Curcas Biodiesel. American Int Journal of research in Science, Technology, engineering and Mathematics. 2016; 16-206: 14-18
9. Suchith Kumar M T, dhananjaya D A. Study on Effect of Injection Pressure on Performance Characteristics of Diesel Engine Using Different Blends of Biodiesel, Int Journal of Emerging Technologies in Computational and Applied Sciences 2014; 14-160: 441-444
10. S. Mahalingam, B. R. Ramesh Babu and B. Balaji. Emission analysis of DI-Diesel engine at different injection Pressures using Jatropha and Rubber seed oil blended with diesel. IOSr journal of Mechanical and Civil Engineering 2014; 78-80
11. K. M. Mriyunjaya Swamy, D. K. Ramesha. The Effect of Injection Pressure and Injection Timing on Performance and Emission Parameters with Algae Oil Methyl Ester Blend as a Fuel for CI engine, Int Journal of Scientific and Research publications, 2015; 5(11): 210-215
12. Jaichandar S, Annamalai K. Combined impact of injection pressure and combustion chamber geometry on the performance of a biodiesel fueled diesel engine. Energy, 2013;55(0):330–9.
13. D.N. Basavarajappa, N. R. Banapurmath, S.V. Khandal, G. Manavendra. Effect of Combustion Chamber Shapes & Injection Strategies onthe Performance of Uppage Biodiesel Operated Diesel Engines. Universal Journal of Renewable Energy, 2, 2014, 67-98.
14. V.S. Yaliwal, N.R. Banapurmath, N.M. Gireesh, R.S. Hosmath, Teresa Donateo, P.G. Tewari. Effect of nozzle and combustion chamber geometry on the performance of a diesel engine operated on dual fuel mode using renewable fuels. Renewable energy, 2016, 93, 483–501.
15. K Srinivasa Rao, G Bhanu Veera Prasad, Dr. A Ramakrishana, “Performance and Emission Characteristics of DI-CI engine using Corn Biodiesel at Different Fuel Injection Pressures” Elsevier, Proceedings of 3rd International Conference on Recent Trends in Engineering and Technology, 2014; 243-247
16. A. Monyem, J. H Van Gerpen., The effect of biodiesel oxidation on engine performance and emission, Biomass and Bioenergy 2001; 20: 317-325