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Effect of Compression Ratio on Engine Performance, Combustion and Emissions in an CI Engine Fueled By VIOME, WCOME and W10V10

Sushanth H Gowda[1]*, Joel Dmello[1], K Raju[1]
[1]*(Department of Mechanical Engineering, St Joseph engineering College, Mangaluru, INDIA)*

Abstract: Benefit for mankind is the key for intensive scientific innovation. In this belief, the research in field of biofuels is one such to create an ecofriendly environment. The work presented here includes the study on the influence of variation of compression ratio(CR) on engine performance, combustion and emissions for the selected biodiesel fuels namely Vateria Indica Oil Methyl Ester (VIOME) B20, Waste Cooking Methyl Ester(WCOME) B20 and W10V10 (Hybrid of VIOME B10 and WCOME B10)along with neat diesel. The main focus is on VIOME due to the reason being very little research is done on the same. The compression ratio levels selected are 17, 17.5 and 18 where 17.5 is standard for the engine design to work on diesel. The increase of the compression ratio favored to increase the brake thermal efficiency (BTE) and reduction in brake Specific fuel consumption (BSFC). The combustion characteristics enhanced at CR 18 due to the temperature assistance. The emissions did not show a significant improvement. The NOx levels were observed to be high whereas the CO levels dropped due to the better combustion.
Keywords: Compression Ratio (CR), Brake Thermal Efficiency (BTE), Combustion and Emission.

I. INTRODUCTION

It is well recognized truth by all concerning the fossil fuel diminution and also the harm to the nature by the use of the same. The fast-moving world, development of science, expansion of the economy necessitates the use of engines and fuels to run the same. The scientist community along with the environmentalists have reported on the adverse effect of the pollutants emitted from the engines or burning of the fossil fuel. [1]–[3]. This concern has raised the young researchers to work on the alternative fuels and also those fuels which are environmentally friendly. Biodiesel is commonly yielded from the vegetative and animal resources. Here while selecting the feedstock utmost care has to be taken such that the food cycle is not disturbed. This has made the policy makers and the associated officials to prepare the governing rules in wise selection of the edible bio stock [4]–[6].

The main focus is given on the preparation of biodiesel from Vateria Indica being the new biofuel and very less research is done. In search of the non-edible feedstock and availability in local areas, Vateria indica found to be the suitable one and also meagre research is done on this feedstock. Vateria indica is yielded in the parts of south zone within Asia and majority in western Ghats of Karnataka, the seeds are commonly called by name Dhupa. These trees yield once in two years around 400 to 500 kg per hectare[7], [8]. The Vateria indica has few medicinal benefits too and studies have revealed the presence of 20 to 22% oil [8]. Gowda et.al stated in their research the existence of the FFA levels more than 6 in oil borne through Vateria indica seeds. Also, the want of two step transesterification is presented so as to make the oil feasible for use, which reduced the tendency to solidify at room temperatures[9]. Awolu and Layokun too reported on the oil yield from neem oil, which demanded the want of two step transesterification as it acquired the FFA levels greater than 4.5, also the procedure helped in reduce of the fuel viscosity [10].

Noting on the handling of the biodiesel in the engine the essential concern for the researchers is on the subject of lesser need towards engine alterations, combustion characteristics, performance, and the emissions. During the factors considered in concern to application of bio diesel preference weightage is offered for the fuel which needs lesser engine modifications. Bio oil yielded from the Jatropha by pramanik et al demonstrated by working the CI engine devoid of physical modifications. Literature is obtainable stating, 45 to 50% of the bio diesel is in capability to switch over diesel fuel deprived of the need to physical engine modifications. Adding to it the engine performance too improved [11]. The biodiesel viscosity is higher which result in difficulty for atomization during the fuel injection and also the vegetative oils cause the clogging of the fuel lines and sticky valves. The oxidization stability and the cold flow properties are the other associated problems which challenges the researchers [12][13]. Blended biofuels in similarity to the neat diesel found to possess short ignition delay. The existence of the abundant oxygen levels resulted in higher combustion temperature[13]. Studies have shown interaction of the biodiesel with the materials of engine owing to the chemical attributes. The characteristics being distinctive followed in the tribological attack and also deterioration of elastomer components[14]. This causes the fuel starvation and also effects in the starting issues of CI engines. Being renewable, the biodiesel feedstock drastically reduces CO_2 emissions from the engines. Studies have been targeted to investigate the cause of several engine factors and emissions using neat biodiesel fuel in CI engines. Increase of compression ratio, injection pressure and decrease or retard of spray timing lessened the NOx emissions[15]. Studies pertaining to variation in compression ratio and fuel injection timing for different loads have shown an increased BSFC as well as exhaust gas temperature for increased proportions of biodiesel at compression ratios of 18:1 to 20:1 and injection timing of 35°-45° before TDC. But advancement in injection timing and raising the compression ratio have shown a reverse trend [16]. Engine performance using cottonseed oil methyl ester (CSOME) on a diesel engine for different blends revealed that for lower blends there was a slight increase in engine torque and suggested that lower content of CSOME will be as replacement for diesel fuel with no engine modification [17].Hosmath et al. have investigated on HOME and CNG and inferred that increase in BTE and a reduction in emissions except NOx at a high compression ratio. With the advancement of fuel injected time, pressure of injection and compression ratio, increases the peak pressure and heat release rate[18].

Going through the various research inferences, in this study concentration is given on to find the suitability of the oil yielded from the vateria indica to be used as the alternative fuel for diesel. The solvent extraction method is employed here to reap the oil from the pulvarised seeds using the soxhlet apparatus. The prepared biodiesel is compared with diesel, biodiesel prepared from the waste cooking oil and the hybrid biodiesel yielded from the Vateria indica and waste cooking oil. The first importance is given on the yield of biooil from the Vateria indica seeds.

II. METHODOLOGY FOR OIL EXTRACTION FROM VATERIA INDICA SEEDS.

Fig 1 Vateria indica seed and plant

Table 1Fatty Acid Composition (Chemical Composition)

Fatty Acid	**Percentage**
Myrstic acid (C 14:0)	0 -1.0
Palmitic acid (C 16:0)	9.7-13.0
Stearic Acid (C 18:0)	38 - 45
Arachidic acid	0.4-4.6
Oleic acid	42.0-48.0
Linoleic Acid	0.2-2.3
Linolenic Acid	Up to 0.5

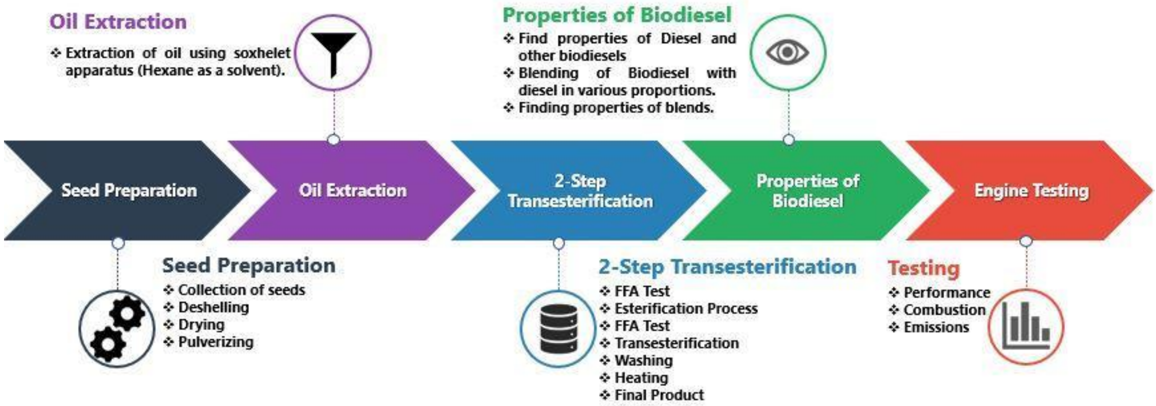

Fig 2 Flow process

Table 2Fuel Properties of High-Speed Diesel and VIOME B10 biodiesel

Fuel Property	Diesel	VIOME	WCOME	VIOME B20	WCOME B20	V10W10	ASTM Standard
Density (kg/m3)	830	870	877	838	839	839	ASTM D 1298
Kinematic Viscosity at 40^{0}C [cst]	3.03	5.4	4.9	3.5	3.4	3.46	ASTM D 445
Calorific Value (kJ/kg)	42000	38700	37100	41340	41020	41170	ASTM D 868
Flash Point (^{0}C)	59	117	173	71	86	76	ASTM D 93
Fire Point (^{0}C)	65	123	181	77	89	82	ASTM D 93

The process involved in the current study is as shown in Fig 2. The extraction of bio oil from Vateria Indica seeds after pulverization is done by employing the Solvent extraction method with aid of hexane as an agent. A 2-step transesterification process has been carried out to obtain Vateria Indica biodiesel. The fatty acid compositions the FFA levels of neat Vateria Indica oil was found to be 8.96, it was not possible to extract biodiesel by transesterification process in a single step. The FFA number is lowered in the first step by adding sulphuric acid as a catalyst with methanol and then it has been transesterified in the second step. The NaOH with methanol is utilised as a catalyst for transesterification. The process was carried out at 60° temperature for duration of 2 hours. The mixture can settle down overnight to segregate the glycerol layer and biodiesel. The obtained biodiesel from Vateria Indica is blended with diesel to study the engine performance as well as emission characteristics. The properties of Vateria indica oil is shown in Table 1. The details of fuel properties selected for the study is shown in Table 2.

III. EXPERIMENTAL SET UP

The experimental setup consists of a computerised variable compression ratio Kirloskar-TV1 Diesel Engine Test rig. The emission testing facility is cascaded to the test rig with electronically generated emission report. Specifications of the test rig are recorded in theTable 3.

Table 3 Specifications of the Diesel engine test rig

Particulars	Details
Make	Kirloskar TV1 engine
Type	4 stroke water cooled
Cylinders	1
Bore - stroke	87.5 mm – 110 mm
Maximum power [kW]	3.5 kW
Dynamometer Type	Eddy current

Injector Hole Diameter	0.3 mm
No of Holes	3
Speed [rpm]	1500
Compression ratio	12:1 - 18:1
Injection timing	23 BTDC

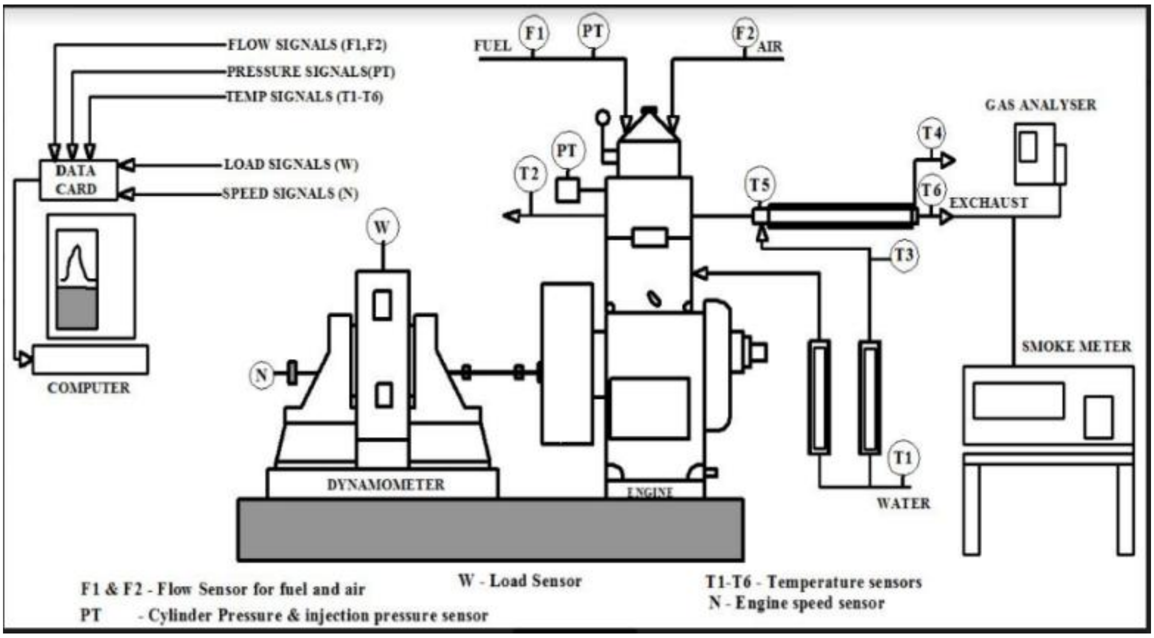

Fig 3 Schematic diagram of computerized diesel engine test rig

IV. RESULTS AND DISCUSSION

The testing has been carried out on a computerized diesel engine test rig. For neat diesel,the tests were conducted for compression ratio levels of 17, 17.5 and 18. A standard injection pressure of 200 bars was maintained at 1500 rpm of engine speed. The same settings were repeated for Vateria Indica B20, waste cooking bio diesel blend B20, V10W10 blended with diesel to study the performance and emissions. The test results were recorded for 0, 20%, 40%, 60% & 80% load conditions. The emissions were recorded for the maximum load acting on the engine.

IV.1 Discussion on Performance

IV.1.1 Brake Thermal Efficiency:

During the test of the biofuel on the diesel engine, smooth performance was noted without any heavy noise or the uneven speeds. in order to yield the better results, the engine was run for two to three minutes for the stabilization under varied load and for accurate results. Brake thermal efficiency is considered as of primary importance to study the performance the reason being it relates the researcher the ability of the engine as well as to liberate the thermal energy and give out as useful mechanical power as rotation of the crank shaft.

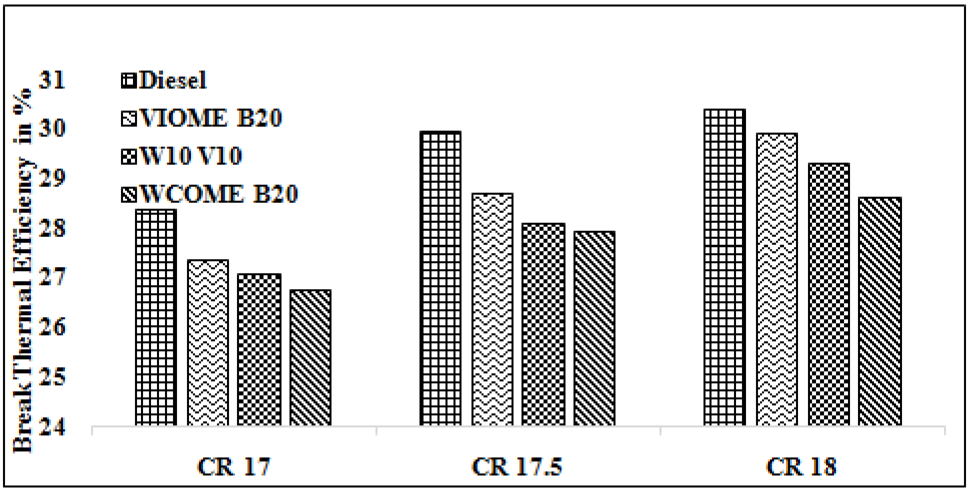

Fig 4 Brake thermal efficiency at 80% load for experimented fuels

The study reflects on the liberation of thermal efficiency against selected fuel at three levels of compression ratio, that is 17, 17.5 & 18. The diesel engine being in capacitance to vary the compression ratio, employing the standard sims provided by the suppliers the compression ratio was varied. CR 17.5 is best suited for the diesel considered as standard by the suppliers. The experimental data demonstrates on influence of risein compression ratio towards thermal efficiency referring to case of fuels opted for study. Variation of the CR from standard to CR18 gave 1.4% increase of thermal efficiency. Evaluating the biodiesel performance VIOME B20 blend developed 4.2%, W10V10 gave 4.3% and the blend of two oils with diesel resulted in 2.5% rise of thermal efficiency. For the compression ratio 17 the energy liberation is less in accordance with the standard CR rating. Hence the CR 18 is considered for discussion. The higher compression ratios are preferred for the better energy liberation from the biodiesel [19][20]VIOME B20 and W10 V10 at the CR setting of 18 developed 29.92 % and 29.32% BTE which is in close competition to diesel fuel. The upsurge in combustion pressure due to the increase CR results in better torque characteristics [21]. The biodiesel observed to be good providing engine performance in comparison to the other two.

IV.1.2 Brake Specific Fuel Consumption

The brake specific fuel consumption decreases as the compression ratio is increased from CR17 to CR18. The biodiesel is observed to give the better decrease in BSFC. This behavior is predicted due to the reason being the lower volatility of fuel and also the cetane number [20].during the transition of CR value from 17.5 to 18, 3.5% in diesel, 3.4% in VIOME B20 blend, 3.4% in WCOME B20 variation of BSFC levels observed. Due to lower energy content in biodiesel with respect to diesel alone the BSFC values are slight at higher levels for biodiesel[16]. The variation of the BSFC is observed inFig 5.

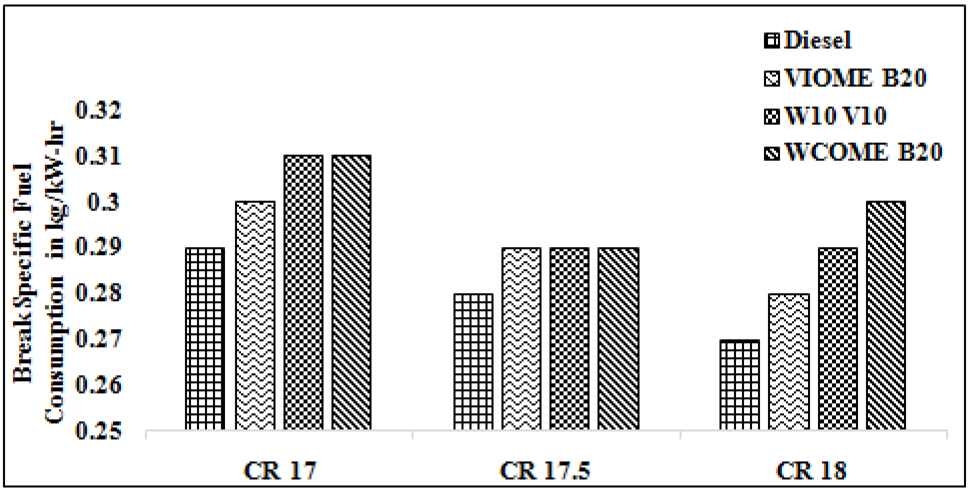

Fig 5 Brake Specific Fuel Consumption

IV.2 Emissions

IV.2.1 Unburnt hydrocarbons at full load.

The UBHC emissions are slighter in biodiesel at diverse range of compression ratio as one sees with reverence to the diesel in Fig 6. The cetane number along with levels of oxygen content in the biofuel is one reason to get this behavior[22]. The VIOME biodiesel owe higher levels of oxygen content being vegetative in feedstock. The unburnt hydrocarbons are also the result of the incomplete burning in combustion chamber. But the rise of the CR contributes for pressure rise boosting the combustion process[23]. Discussing on the variation UBHC in change of CR from standard to 18, decrease in levels by 4% in diesel, 4.3% in V10W10 and 8.6% in WCOME is evident from the study. The biodiesel blend makes the ignition delay shorter thus it also contributes to reduce the HC emissions. The reduced HC emissions discloses note on clean burning of fuel.

IV.2.2 Carbon Monoxide

The Fig 7 shows the CO emission levels of the selected biodiesel against the variation of the compression ratio 17,17.5 and 18. The absence of the complete combustion gives out the CO emissions and this emissions impacts the human lives in larger levels[24]. In this study it is interesting to know that VIOME B20 biodiesel yields lesser amounts of the CO and also decrease in emissions is evident as the CR increases to 18. The high levels of the oxygen content in vateria indica biodiesel along with the influence of elevated pressure as the CR increases the levels of CO drops giving out the CO_2. But slight level of smoke is observed during the experimentation run. Higher levels of CO are evident in WCOME B20 at lower compression ratio of 17 and 17.5.

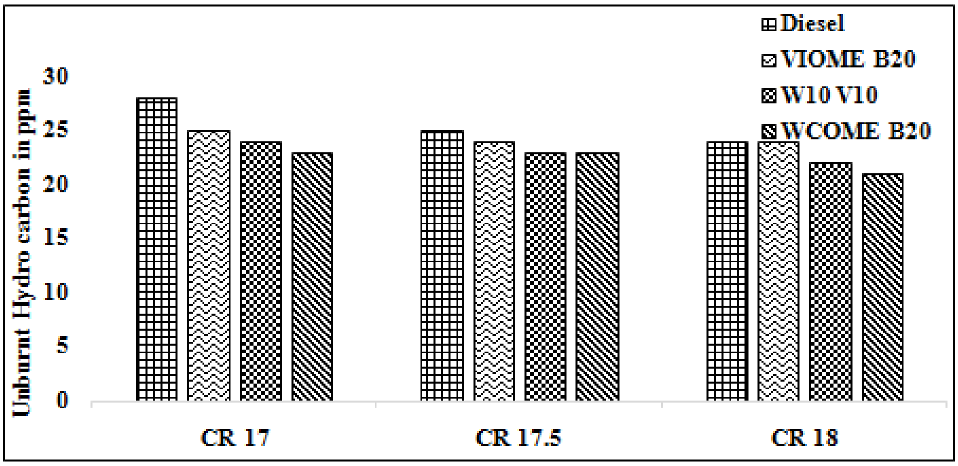

Fig 6 UBHC levels at full load

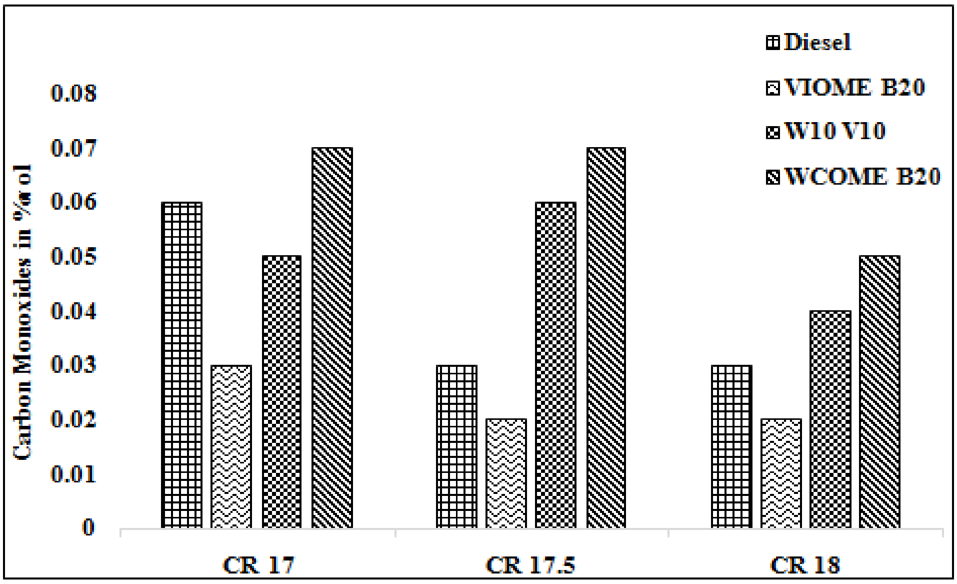

Fig 7 Levels of Carbon monoxide of selected fuels vs compression ratio

In considering the variation from CR 17.5 to 18 being significant for diesel and VIOME there is no change, but 33% drop of CO in W10 V10 and 28.5 % drop of CO levels in WCOME B20 is evident. Regarding the diesel and VIOME B 20 the significant change is noted as the CR is varied from 17 to 17.5 that is 50% drop on levels of CO in case of diesel and 33% drop of CO levels considering VIOME B20. The biodiesel yielded from the waste cooking oil necessitates higher temperature for the proper combustion in relation to diesel.

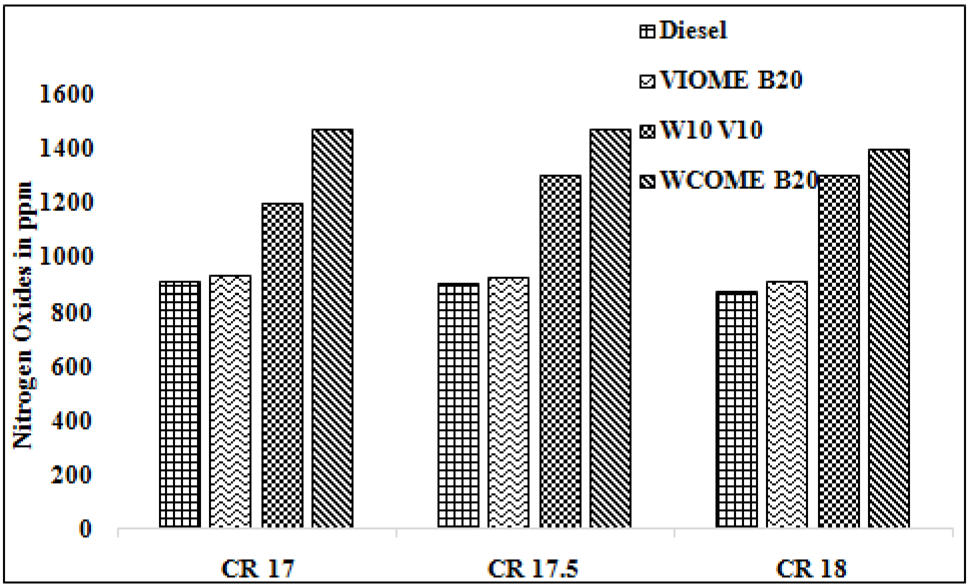

Fig 8 NOx levels of the fuels with variation of CR

IV.2.3 NOx Emissions

In CI engines the oxides of nitrogen are released in the emissions due to the adiabatic flame temperature which relies on the peak pressure and temperature in engine cylinder[25]. The Fig 8 exhibits the levels of NOx of selected fuels in this study against the CR. There is very minimum influence on NOx as the CR level rise in case of the diesel fuel. The NOx levels drop from 912ppm to 875ppm. The same is evident to VIOME B 20, the variation being lowering of value from 932ppm to 912ppm. The W10 V10 blend exhibits almost stable trend is evident as the CR levels increased. The change being 1197ppm, 1299ppm and 1300ppm respectively for CR 17, 17.5 and 18. The biodiesel yields greater levels of NOx as compared to diesel. The peak pressure promotes the cetane number in biodiesel along with the oxygen levels for development of NOx levels. The expanded ignition delay and additional amounts of fuel injected due to high density may be the other associated justifications for release NOx [26].

IV.2.4 Smoke Opacity:

For the selected fuels with respect to the variation of compression ratio the smoke opacity levels are graphical represented inFig 9. There is a mixed response in regard to the smoke opacity for the different fuels. The smoke at the emissions is due to several associated reason amongst which the possible at this study being the poor atomization of the biodiesel, especially WCOME B20 and W10V10. Poor atomization results in meagre vaporization. The biodiesel selected for study possesses higher density, these heavier molecules slows down the combustion process speed and this develops smoke. And also, the greater viscosity levels decrease the fuel jet Reynolds number [27][28]the lower level of Compression ratio 17 facilitate the fuel to give out more amounts of smoke. At CR 17 the smoke opacity in %HSU are 53.9,53.3,57.8 and 63.4 for diesel, VIOME B20, W10 V10 and WCOME B20, respectively. At CR 17.5 the smoke opacity in %HSU are 46.4,44.4,50.1 and 52.5 for diesel, VIOME B20, W10 V10 and WCOME B20, respectively. At CR 18 the smoke opacity in %HSU are 53.6,49.8,53.9 and 59.6 for diesel, VIOME B20, W10 V10 and WCOME B20, respectively. For the standard engine compression ratio, the levels of smoke opacity are reasonable in comparison to lower and higher variation.

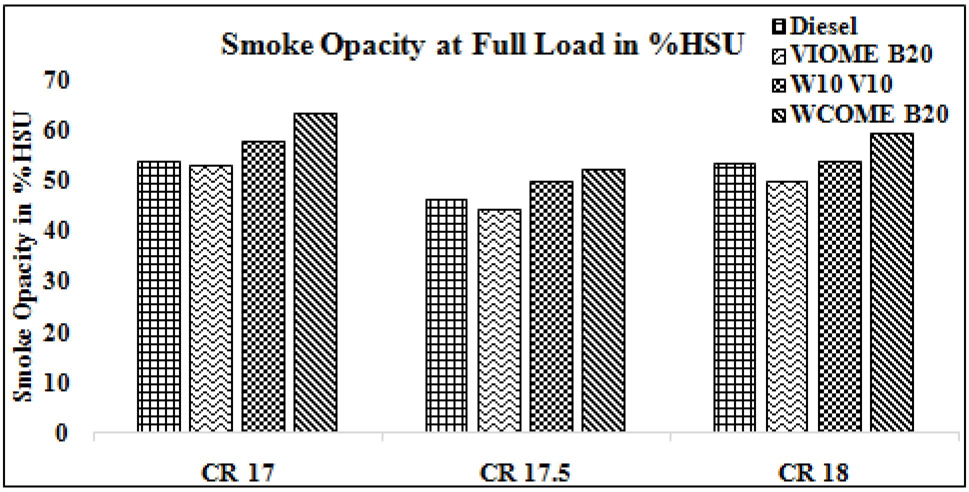

Fig 9 Smoke opacity in the fuels selected for study vs the CR

IV.3 Combustion Analysis

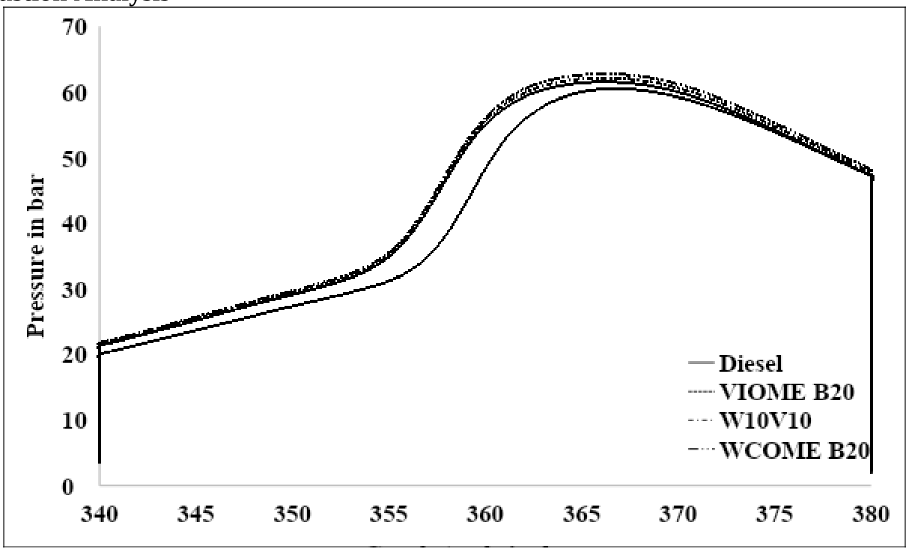

Fig 10 Pressure Rise Vs Crank Rotation for CR 17

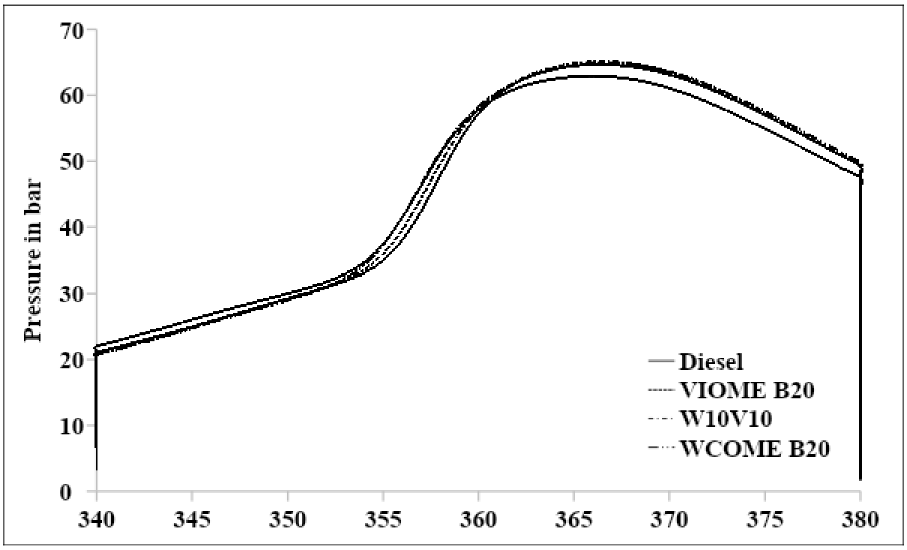

Fig 11 Pressure Rise Vs Crank Rotation for CR 17.5

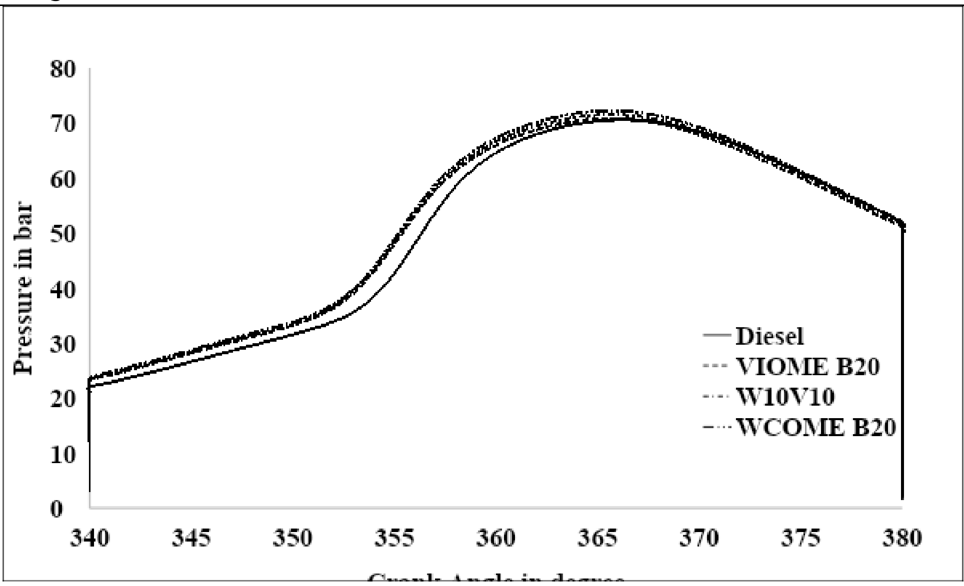

Fig 12 Pressure Rise Vs Crank Rotation for CR 18

The combustion analysis concentrates on the pressure rise, net heat release rate and mass fraction burnt. The variation of the pressure rise with the rotation of crank is shown in Fig 10Fig 11 and Fig 12. It is learnt that the pressure rise in the combustion chamber is recorded for the compression ratio 18. The research recorded pressure values during experimentation for CR 17 are 60.48, 61.53, 62.14, 62.76 bar for diesel, VIOME B20, W10 V10 and WCOME B20, respectively. Similarly, at CR 17.5 the recorded pressure values in bar are 64.66, 62.91, 65.06 and 64.9 for diesel, VIOME B20, W10 V10 and WCOME B20 respectively and lastly for CR 18 the pressure values in bar were 70.58, 70.8, 71.508 and 72.216 for diesel, VIOME B20, W10 V10 and WCOME B20 respectively. These pressures come about at crank position of 366 to 367 degree.

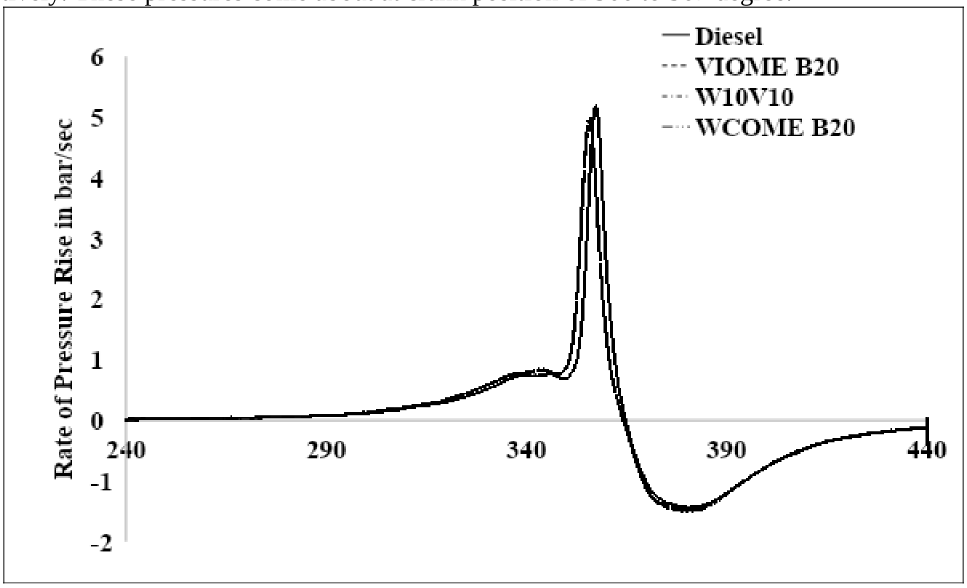

Fig 13 Rate of Pressure Rise Vs Crank Rotation at CR 17

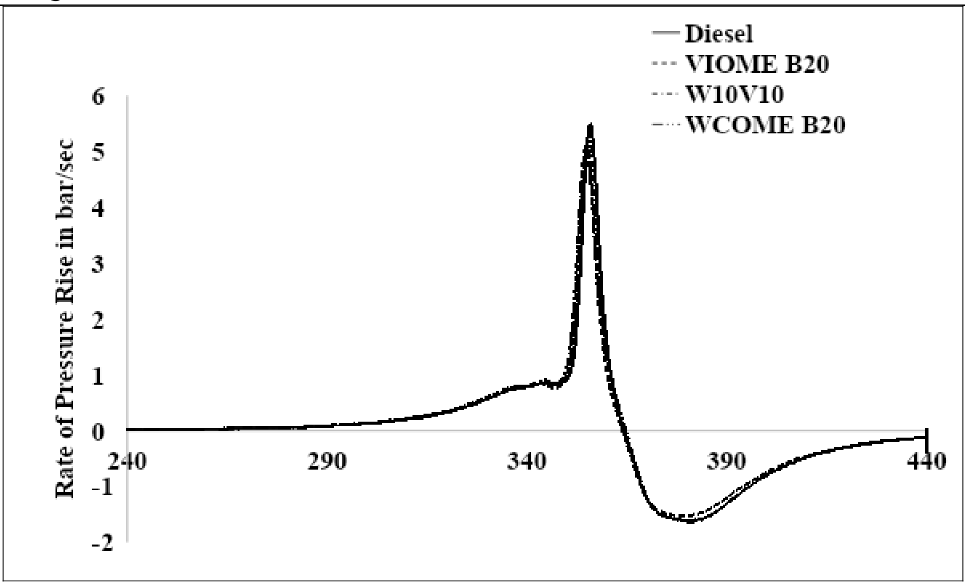

Fig 14 Rate of Pressure Rise Vs Crank Rotation at CR 17.5

The rate of pressure rise with respect to the crank angle is highlighted in Fig 13Fig 14 and Fig 15. The diesel fuel being more volatile in comparison to the biodiesel serves better. The rate of pressure rise is faster in the diesel followed by VIOME B20.

The net heat release rate is employed to see through the initiation of combustion and mass of fuel burnt. The Fig 16, Fig 17 and Fig 18 shows the heat release with respect to the crank position for the selected fuel burnt at three CR selected for the study. The analysis revealed net heat release in the biodiesel VIOME B20, W10 V10 and WCOME B20 are lesser to the diesel fuel. The reason being the lower calorific value in the biofuels [29][30]. The heat release rate for the compression ratio 17 were observed to be 48.7, 44.76, 45.21, 45.652 J/s for diesel, VIOME B20, W10 V10 and WCOME B20 respectively at the crank position of 356 to 357 degree and in same way for CR 17.5 the heat release rate recorded 49.26, 43.63, 45.88, 44.77 J/s for diesel VIOME B20, W10 V10 and WCOME B20 respectively and similarly for CR 18 the results obtained are 47.76, 42.11, 42.53 and 42.95 J/s for diesel VIOME B20, W10 V10 and WCOME B20 respectively.

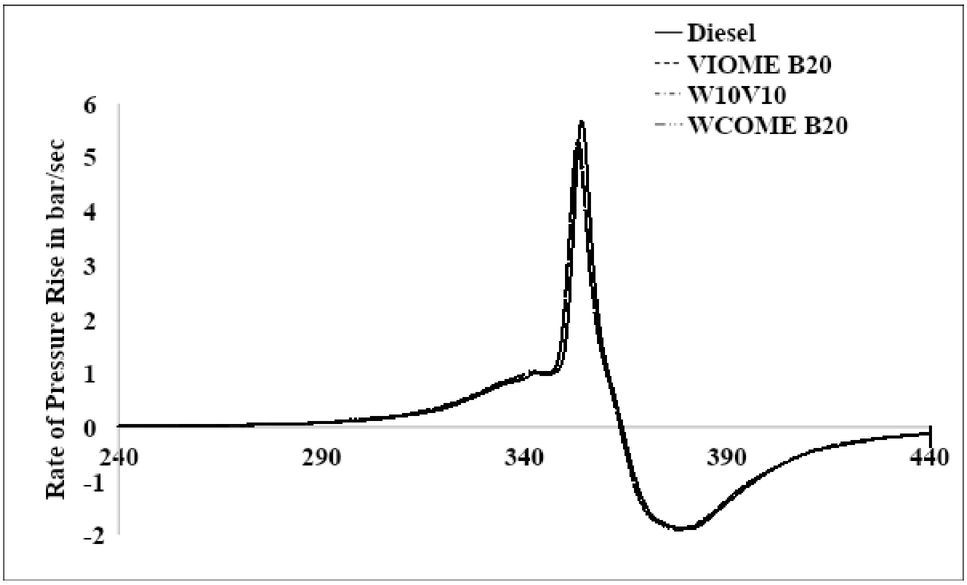

Fig 15 Rate of Pressure Rise Vs Crank Rotation at CR 18

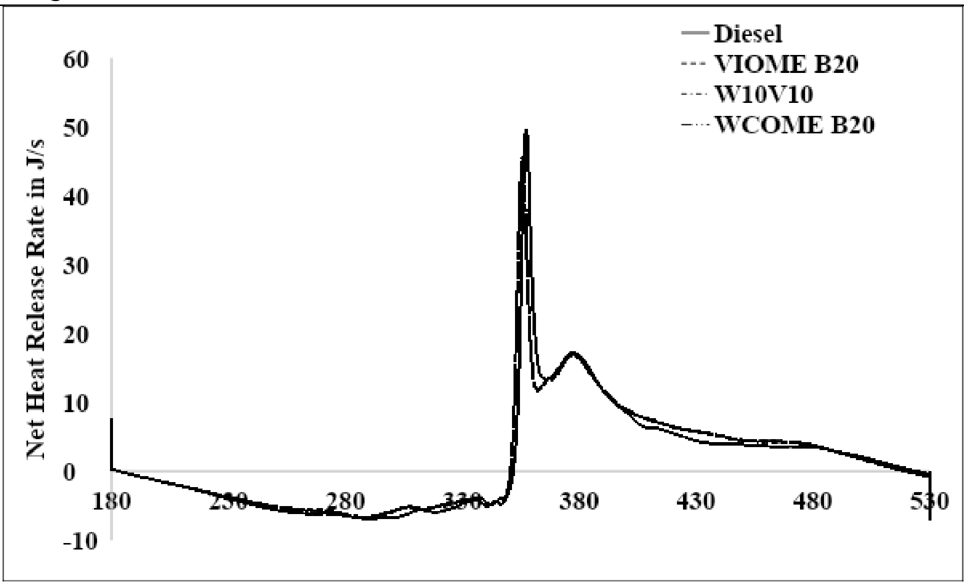

Fig 16 Net Heat Release Rate Vs Crank Rotation at CR 17

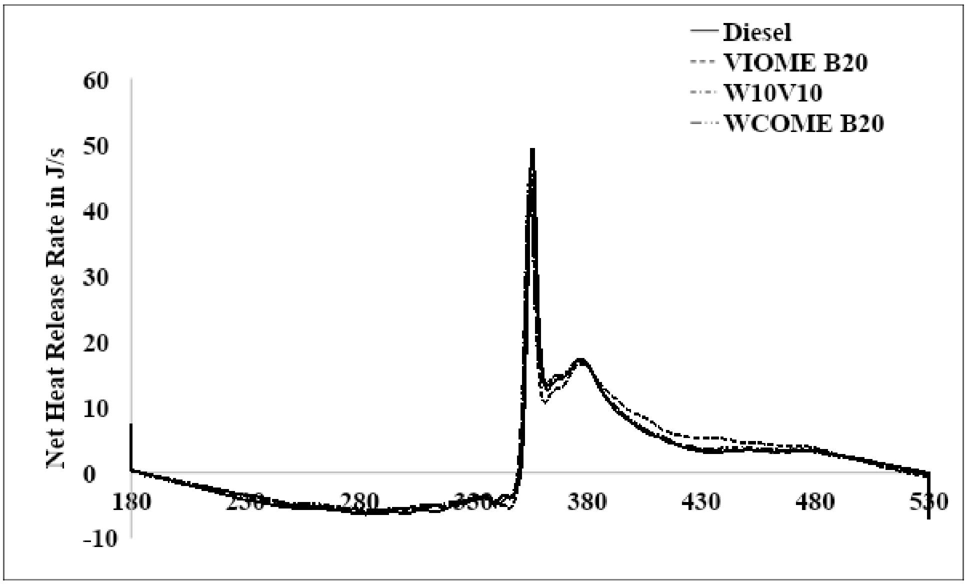

Fig 17 Net Heat Release Rate Vs Crank Rotation at CR 17.5

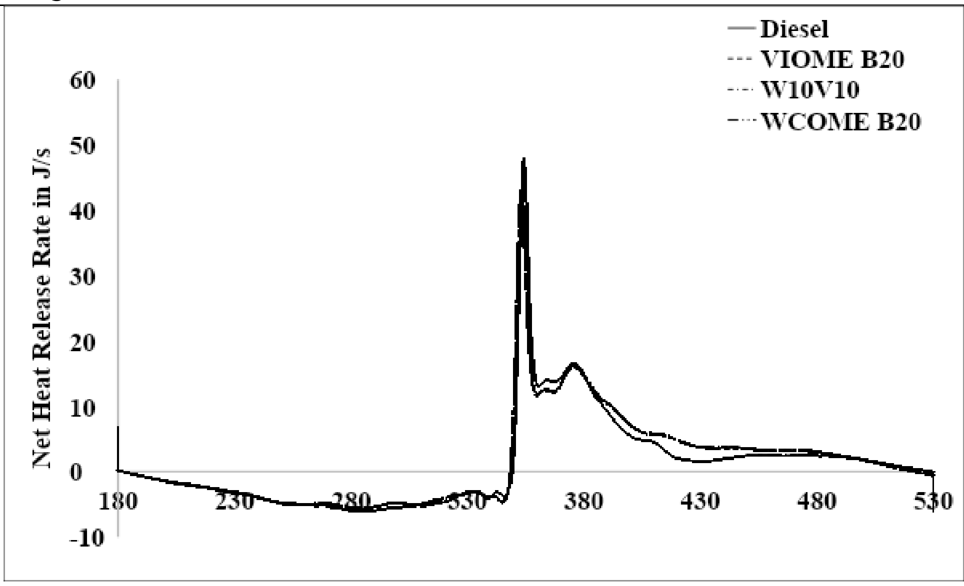

Fig 18 Net Heat Release Rate Vs Crank Rotation at CR 18

V. CONCLUSION

In this study the biodiesel was successfully prepared, and the test run was done on the test rig. The objective her was to learn the behavior of diesel, VIOME B20, W10 V10 and WCOME B 20 with the variation of nearby CR to the standard that is 17,17.5 and 18. The following conclusions are drawn from the study.

1. The raise of compression ratios is beneficial in case of VIOME B20 and W10 V10. At the CR setting of 18 the engine developed 29.92 % and 29.32% BTE for VIOME B20 and W10 V10. At CR 18 the diesel fuel yielded BTE of 30.34% and biodiesel yielded from the waste cooking oil that is WCOME B 20 gave 28.64% BTE.
2. The BSFC levels dropped on increase of compression ratio from CR17 to CR18 this was due to the fuel volatility. The shift of CR from 17.5 to 18, the percentage change in BSFC noted is 3.5% in diesel, 3.4% in VIOME B20 blend, 3.4% in WCOME B20.
3. The close look on emissions at exhaust showed variation in UBHC due to change of CR from 17.5 to 18, decreased the levels by 4% in diesel, 4.3% in V10W10 and 8.6% in WCOME. It indicated clean burning of fuel. The CO emission reduced as the CR increased due to the presence of oxygen content in the selected bio diesel. The variation from CR 17.5 to 18 being significant for diesel and VIOME there is no change, but 33% drop of CO in W10 V10 and 28.5 % drop of CO levels in WCOME B20 is evident.
4. There is very minimum influence on NOx as the CR level rise in case of the diesel fuel. NOx levels are high in biofuels in comparison to diesel fuel. The raised temperature due to the change of compression ratio effects the NOx levels liberated on burning of Biodiesel. The change of compression ratio against the standard in nor appreciable while considering the smoke opacity.
5. The combustion analysis revealed that for the selected biodiesel the heat release in better on higher compression ratio but not better than the diesel fuels the reason being the lower calorific value of biodiesel. The higher compression ratio facilitated better combustion due to the temperature rise and helped in mixing of the fuel. at lower ratios, the lesser volatility and higher viscosity levels in bio diesel proved to be slight sluggish towards heat release.

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