EXPERIMENTAL INVESTIGATION ON INFLUENCE OF ADDITIVES ON PERFORMANCE OF DIESEL ENGINE ALONG WITH EGR FUELED WITH BIODIESEL

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Abstract: India is a country fixated with fuel efficiency and in this regard, petrol vehicles are no match to diesel engines. Diesel engines emit harmful emissions while combustion and cause damage to health and environment. Another major problem is the shortage of conventional fuels especially diesel Zinc oxide is one such exciting nanoparticle because of its properties such as improvement of heat transfer rate. And it increases catalytic properties and provided higher surface to volume ratio. Exhaust gas recirculation (EGR) technology has also been used in the experimentation. A Kirloskar made TV2 diesel engine has been employed to conduct the experiment at varied load. In this experiment Diesel has been considered as baseline reading and three other fuels, that is Biodiesel,Biodiesel+15% Ethanol and Biodiesel+80ppm of ZnO has been considered for comparison purpose. The engine has been run from 0% to 100% load using the 4 fuels and EGR has also been applied and the results have been evaluated, From the results it is revealed that the BTE is increased and BSFC has reduced thus showing that the performance of the engine is improved .The emissions of CO, NOx and PM has reduced and especially CO has reduced all the blends

Keywords: Waste Cooking Oil, Biodiesel, Diesel engine, Performance, emissions, combustion, ethanol, Zinc Oxide, nanoparticle ,Exhaust Gas Recirculation, metal oxide ,oxygenator.

I. INTRODUCTION

Use of metallic additives started from the early 2000s but has been increased recently due to nanoparticles and ease to access to nanoparticles. Also nanoparticles improve properties of fuels acting as Nanocatalyst (1,2). Use of nanoparticles as a catalytic agent has shown several benefits like improvement of combustion enthalpy, shorter ignition delays (the degree of air and fuel mixing and even burning will be enhanced), more thorough combustion and lesser harmful emissons(3). Surface to volume ratio is a very important parameter of a nanoparticle and if it is high ,it provides additional contact surface area for quick oxidation, and in the process releasing nearly twice the energy derived from even the best fuel combustion and molecular explosion(5). Also by varying the surface-to-volume ratio of a nanoparticle, properties such as reactivity, strength and also the electrical properties can be attuned (4).Nano additives reduce harmful emissions and fuel consumption because the metal reacting with water to create hydroxyl radicals, which improve soot oxidation, or by better combustion of carbon atoms in the soot, thereby reducing the oxidation temperature (6-8). Furthermore for nanoparticles, there are numerous number of actives surfaces which improves the dispersion rate, and avoids clogging in the fuel injectors (9,10). Coarse fuel droplets are formed due to high viscosity, and this increase in viscosity is caused when there is increase in nanoparticle concentration. This coarse fuel droplets undesirably affects the fuel penetration and dispersion in the cylinder. Biodiesels have higher kinematic viscosities and this can be compensated by blending biodiesels with oxygenators (11).

The most important additives for diesel engines are oxygenated additives Oxygenated fuel oxygen containing chemical compounds. The property of a good oxygenator is it should capable of mixing in any ratio without separation of its two phases with various fuels. Oxygenated additives assist high laminar flame propagation speed, which make combustion process finish earlier thereby improve engine thermal efficiency and also oxygenators allows the fuel in engine to burn more completely which results is lesser amount of harmful chemicals rescued into the atmosphere (12-14). With the right molecular structure and oxygen content in the fuel, oxygenators can reduce the ignition temperature of particulates(15)Among oxygenators alcohols is a very good option and among alcohols, ethanol is a suitable (16) Ethanol is not carcinogenic and is not flammable like methanol when used as a motor fuel(17).The initial investigations into the use of ethanol in diesel engines started out in South Africa in the late 1970s and continued in the United States and Germany during the 1980s(18-20)Ethanol can be considered a renewable fuel because it can be fermented and distilled from biomasses. It has an oxygen atom and can be considered as a partially oxidized hydrocarbon.Another reason ethanol is a good oxygenator for biodiesel is ethanol tends to decrease kinematic viscosity due to short- reactive carbon chains, and one of the drawbacks of biodiesel as mentioned is higher viscosity. Ethanol also maximizes superficial contact by reducing the surface tension between water and oil(21).

The drawbacks of ethanol are lower calorific value and lower cetane number as compared to diesel, also it is much more corrosive. This can be partially overcome with the addition of biodiesel as the biodiesel has higher cetane number than diesel so the cetane number compensates. Ethanol possesses lower viscosity, auto ignition temperature and lower flash point than biodiesel fuel and its addition in the diesel fuel reduces the lubricity of the blend and creates potential wear problems in modern fuel pump which employ a fuel-based lubrication (22-27).The barriers of using ethanol and biodiesel is that the addition affects properties is mainly stability and volatility. Phase separation occurs at relatively low temperatures due to the breakage of the interfacial film caused by the increase in pressure at lower temperatures and this can be prevented in multiple ways: one of them is through the addition of an emulsifier, which lowers the surface tension of two or more substances, another method is by adding a co-solvent, which modifies the power of solvency for the pure solvent or lowering the diesel aromatic content reduces the solubility of ethanol and also adding an emulsifier, which acts to suspend small droplets of ethanol within the diesel fuel. Solubility of ethanol also depends on the hydrocarbon composition and wax content of the base diesel and biodiesel. (28-36)

Increase in demand of ethanol derived from sugarcane will reduce pollution and strengthen India's resolve towards fulfilling commitments made at the UN Climate Change Conference held in France in 2015 (Paris climate deal). The blending of ethanol in conventional fuels had increased by nearly 300% from 380 million litres in 2013-14 to around 1.41 billion litres in 2017-18. Ethanol generates oxygen when combined with fuel along with improving the engine efficiency thereby reducing harmful emissions, with the use of ethanol in India can reduce its pollution problem. This move will reduce India's energy import dependency helping the country save $1 billion in crude oil imports next year. Inview of keeping this in mind the government has given its approval for fixing higher ethanol price derived from different raw materials for the 2019-20 sugar season during ethanol supply year from 1 December 2019 to 30 November 2020 stating as ethanol availability is expected to increase significantly because of higher prices being offered for procurement of ethanol from all the sugar cane based routes, subsuming partial sugar cane juice route and 100% sugar cane juice route under sugar cane juice route and for the first time allowing sugar and sugar syrup for ethanol production. Ethanol's growing importance comes in the backdrop of the Organization of the Petroleum Exporting Countries (Opec)-plus arrangement extending its compact for production cuts at a time of supplies from Iran and Venezuela drying up and tension escalating in the Persian Gulf. Increasing ethanol production will help India save valuable forex reserves, given that the country is the world's third largest oil importer and imports more than 80% of its oil requirements and around 18% of the natural gas it needs. This comes against the backdrop of India using only around 6% of the world's primary energy despite it having 18% of the world's population. The production of ethanol worldwide has increased by nearly 200%, from nearly 40 million liters in 2007 to more than 85million liters in 2012 and is expected to grow by 500% by the end of 2025.

Reduction of emissions achieved with exhaust gas after treatment and improved combustion processes (37).Exhaust Gas Recirculation (EGR) has widely been acknowledged to be the most feasible method to reduce NOx emissons with great effect. In EGR a small portion of the exhaust gas is recycled to the engine and which reduces the oxygen available for the harmful emissons and thus leading to reduction of the harmful emissons. Hot EGR is a widely used technique in EGR which basically keeps the exhaust temperature inflated which diminishes NOx,Smoke Opacity and HC The recycled exhaust gases into the engine intake air rises the specific heat capacity of the mixture and reduces the oxygen concentration of the intake mixture. These two factors combined lead to significant reduction inharmful emissions. Another point to note is that EGR doesn't not affect the fuel efficiency (38, 39).

Waste cooking oil (WCO) is a promising feedstock and numerous of the biodiesel production facilities are presently utilizing it and its 90% renewable. There still isn't a robust way to collect waste cooking oils castoff from domestic usage and disposing it through the drainage system is harmful for the environment as it results in water pollution. More than 75% of Waste cooking oils comes from domestic usage and controlling its dumping requires a lot of investment (40, 41).Using this discarded WCO for production of biodiesel is one of the best ways to properly dispose it and would also decrease the reliance on diesel. (42) Collation of WCO from different sources can therefore result in heterogeneous feedstock streams, and standardizing the characteristics of WCO is therefore inherently difficult. High-grade waste vegetable oils that are deemed safe for consumption by animals outside of the EU (and are therefore not waste materials) are redirected from animal feed to biofuel production as suppliers will pay more for a waste-derived biofuel than they would for virgin oil(43). Between 2011 and 2016, the utilization of WCO has increased steadily, resulting in a 360% rise in its use, increasing from 680,000 tonnes to 2.44 million tonnes(44) A major stimulus for increased WCO Biodiesel consumption is the fact that it reduces emissons which are one of the shortcoming of diesel engines.It does this by increasing the oxygen content in the fuel which leads to better overall combustion and is extremely useful for curtailing NOx formation .Use of biodiesel has been on the rise especially in the European Union because it reduces dependency on fossil fuels and helps shrink greenhouse gas effect, and this usage is also motivated to meet the targets set by the European Parliament. WCO is one of the main sources for biodiesel production(45) WCO can be used in different types of diesel engines with no penalty on efficiency and significant diminution of Smoke opacity ,CO ,HC and NOx emissions with respect to diesel.(46-54)

In this present work, WCO has been used as biodiesel along with metal oxide additives like Zinc Oxide nanoparticle and oxygenator additives such as ethanol has been used. Exhaust Gas Recirculation has been employed for further reduction of emission..

Nomenclature

CFME	Chicken Fat Methyl Ester
B100	Biodisel 100%
D	diesel
ZnO	Zinc oxide
BP	Brake Power
BTDC	Before Top Dead Center
BTE	Brake Thermal Efficiency
HRR	Heat Release Rate
B20	20% biodiesel + 80% Diesel
CO	Carbon monoxide
EGT	Exhaust Gas Temperature
UBHC	Unburnt Hydrocarbon
NOx	Oxides of Nitrogen
ppm	Parts per million
LPH	Liters per hour
B20CFME	20% Chicken fat methyl ester + 80 % Diesel
B20CFMEZNO	20% Chicken fat methyl ester + 80 % Diesel+ Zinc oxide

II. MATERIALS AND METHODS

This section describes the biodiesel preparation procedure, properties of tested fuels and Experimental set up.

2.1. Transesterification

Current experimentation work considered transesterification process to obtain biodiesel (55). Transesterification process consists of 2 steps namely Acid Transesterification and Base Transesterification. In acid transesterification, WCO is heated up to 50°C. Then Methanol is added to preheat WCO. After this reaction the bottom deposit is detached from the reaction (Base Transesterification).The obtained mixture is heated for 45-55 minutes in the presence of KOH (Potassium Hydroxide) and methanol. Once the reaction is completed, the products are permitted to distinct into two deposits .The bottom deposit, which contained glycerol, is removed. The ester leftovers in the upper deposit.Figure1 demonstrates the complete operation of the Transesterification method. The fuel properties of Diesel, WCO with and without 15% Ethanol were determined and tested to meet the ASTM standard requirement. Heat value of the fuel is measured by using Bomb Calorimeter, Kinematic viscosity is measured by using Capillary tube Viscosity Test Method, flash point is marked by using open loop method and measured of density is carried out by using two separate measurements of mass and volume (see Fig.1.). All the properties of verified biofuels are tabulated in Table.1.

The nanoparticles are dispersed into a mixture of Waste cooking Oil biodiesel-diesel fuel at the recommended composition (20 % by vol. of WCO and 80 % of diesel fuel) with the help of an ultrasonicator (Hielscher UP200S40) for 35 minutes at a frequency of 24 kHz. The ultrasonication technique is the an ideal method to disperse the nanoparticles in the biodiesel blend to avert the agglomeration of nanoparticles by means of pulsating frequencies to disperse nanometer ranges into the blend. The Zinc Oxide (ZnO) nanoparticles of average size of 30 to 50 nm with detailed specifications list in Table 2. The biodiesel fuel prepare from transesterification of chicken waste fat oil. The chicken waste collected was cleaned by washing it in water and it is heated up to 120^0C to lose all its moisture content and was strained which in turn filtered it. After filtration process, purified chicken oil was obtained. The nanoparticles are weighted 40ppm of mass fraction and added to biodiesel blends by using ultrasonicator set to dissolve the nanoparticles completely into the fuel (B20CFME ZnO 40ppm). The same principal is applied for 80ppm and 120ppm to prepare ZnO and biodiesel blends (B20CFME ZnO 80ppm, B20CFME ZnO 120 ppm). The properties of the fuels are appeared Table 1.

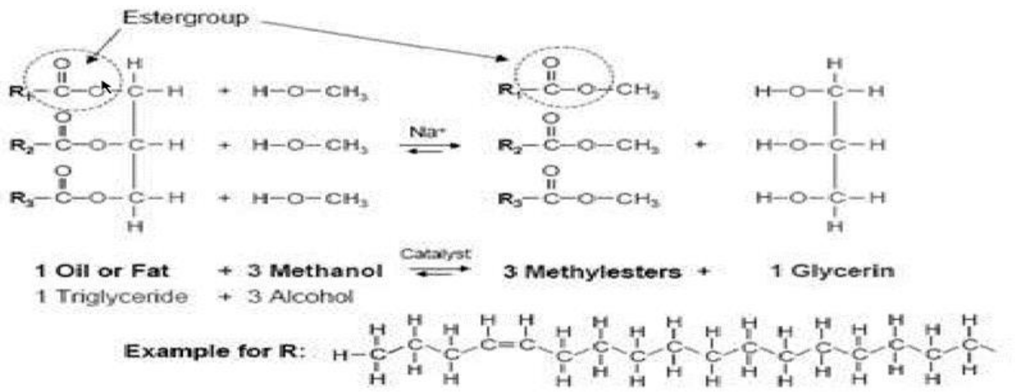

Fig.1. Transesterification of Oil

Table 1. Properties of fuels used for Testing

PROPERTIES	UNITS	DIESEL	WCO	WCOME	B20WCOME	ETHANOL	B20WCOME+15%ETHA..L
Density	kg/m^3	830	914	887	842	790	828.75
Kinematic Viscosity	at 40 °C, cst	3.05	4.3	5.83	4.01	1.2	3.765
Calorific Value	kJ/kg	44.5	29	38	39.2	27.9	36.8
Flash Point	°C	60	307	150	98	14	79
Cetane Index	-	40	53	51.48	51.48	110 (Octane Number)	48

Table 2. Zinc Oxide Properties

Sl. No.	Parameters	Zinc Oxide(ZnO)
1	Manufacturer	Nano Research Lab
2	Chemical Name	Zinc Oxide
3	Form Colour	Powder White
4	Particle Size	25-50 mm
5	Specific Surface Area	12 m²/g
6	Purity	99.97%

2.2 Experimental Setup and method

The specification of engine as shown in Table.2.

Table 2. Specification of test engine

Parameters	Specifications
Engine	Four Stroke Single Cylinder
Make	Kirloskar
Number of cylinder	One
Speed	1500 rev/min
Bore	85 mm
Stroke length	110 mm
Compression ratio	17.5:1
Starting	Cranking
Working length	Four Stroke
Method of cooling	Water cooled
Method of ignition	Compression ignition
Dynamometer	Eddy current

2.2.1 Experimental setup

The experimental results will certainly have error and uncertainties, which can rise from the incorrect calibration of instruments due to excessive handling and mishandling, surrounding conditions, experimental test conditions and planning, surveillance and reading. The errors which are gotten become a hindrance to obtain accurate results. Thus to nullify these errors, tools and methods from mathematics and statistics are used. Generally the method used is repetition of the taking data from the experimentation (at least 3 times) and finding the mean in order to minimize the error which may occur. (56) Measurements of uncertainties were calculated and results are shown in Table 3 .The uncertainty of the experiment was 1.8445%..

Fig. 2. Diagram of the engine setup

Table 3. Error analysis and uncertainty

Measurements	Accuracy	Uncertainty
Speed	±3 RPM	± 0.3%
BSFC	±3 kg/KWh	± 0.35%
Power(KW)	±0.3KW	± 0.40%
CO	±0.02%	± 1.0%
NOx	±7 ppm	± 0.7%
In cylinder pressure	±0.1 bar	± 0.2%
Temperature	±1°C	± 0.1%
HC	±7 ppm	± 0.7%
Torque	± 0.1Nm	± 1%

III. RESULTS AND DISCUSSION

Exhaustive experimentation has been made with varied load and the readings have been tabulated and plotted in graphs. The different characteristics which was measured of the engine fueled with biodiesel are performance (BTE-Brake Thermal Efficiency and BSFC-Brake Specific Fuel Consumption),combustion(P- θ and Heat Release Rate),Emissons(NOx-Nitrogen Oxides , CO-Carbon Monoxide, HC-Unburnt Hydrocarbons, Smoke Opacity)

3.1 Performance Analysis

3.1.1 Specific fuel consumption

From Fig.2, at full load there is a decrease of BSFC by 7% when compared to diesel as ZnO acts as an oxidizing agent which boosts the combustion process and improves the A/F Ratio reducing the BSFC(66)Shorter ignition delay caused by Zinc Oxide leads to better combustion and thus more work is gotten for the same amount of fuel thus lowering the BSFC (67).ZnO will minimize pour point and increase the flash point properties of the blends which improve atomization and better mixing process reduce BSFC. Nanoparticles have a catalyst effect which lessens oxidation temperature which is instigated from lower oxidation energy with ZnO (68-71).

For the ethanol, blended fuel the decrease in BSFC is almost similar to Zinc Oxide blended fuel, approximately 8% when compared to diesel .For ethanol blended fuel there are 2 main aspects to be considered here, self-ignition temperature and boiling point. The auto ignition temperature of ethanol is greater than that of diesel but for boiling point it is vice versa. Which means that diesel will initiate the ignition but due to the boiling point of ethanol being lower, it will evaporate before diesel and will support the progress of the combustion through the unburned blend spray thereby reducing consumption of excess fuel. Moreover, because of the inferior latent heat of the ethanol reduction in dissociation reactions could be anticipated (72) again reducing the specific consumption of fuel. Another reason is the additives decreases the mass flow rate because the density decreases as we increase the additives %.

When EGR is applied to the blends, for Zinc oxide blended biodiesel there is an increase of nearly 12% when compared to diesel and for ethanol it is 10%. By applying EGR the BSFC rises because of altering the A/F(Air fuel) ratio, which creates an oxygen deficit, dilution effect and the dwindling burn rate, making stable state of combustion harder to attain(73, 74).

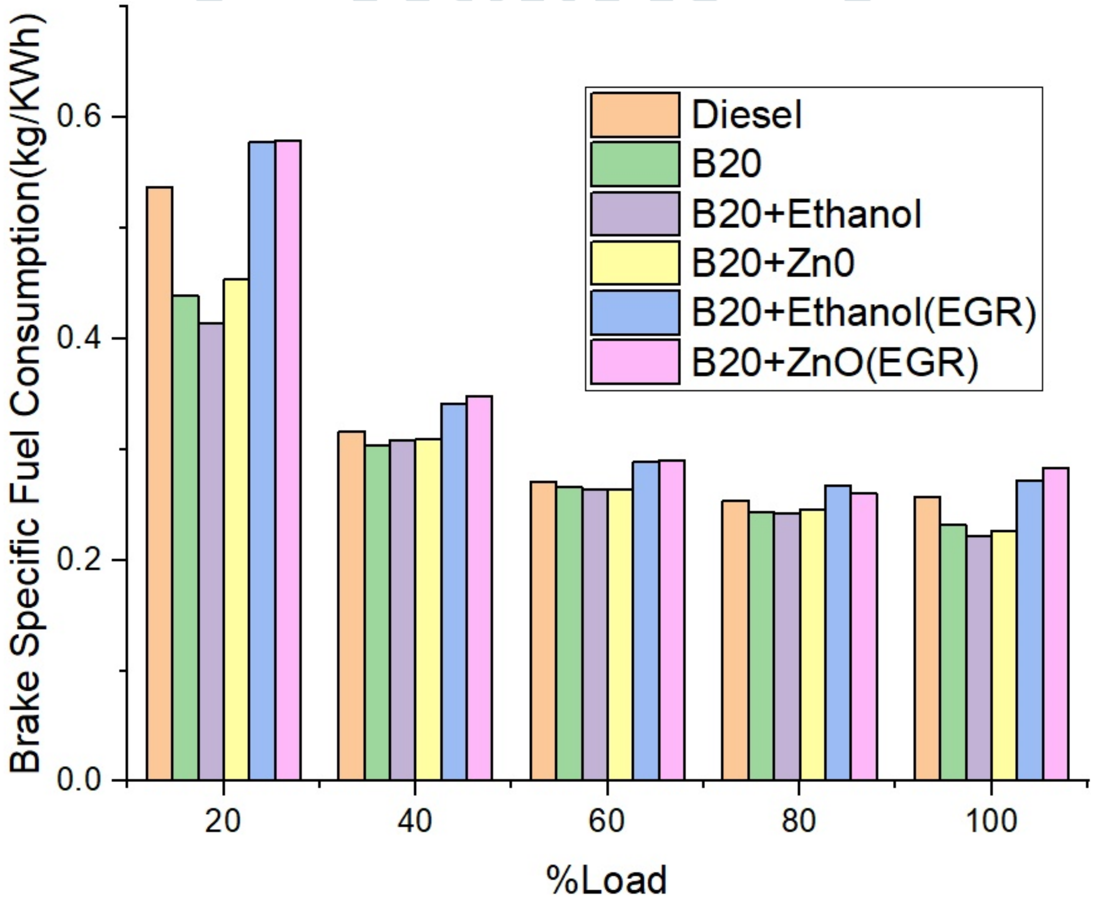

Fig.2.Break Specific Fuel Consumption vs % Load

3.1.2 Brake Thermal Efficiency

Fig.3. shows the variation of Brake Thermal Efficiency(BTE) with Load, the Brake thermal efficiency at full load increases by 4% for biodiesel the improved BTE can be accredited to the improved diffused combustion would have also resulted due to oxygen enhancement caused by the blends and this is supported by the fact that HRR process almost occurs at the same location for the blends (57) By the addition of ZnO there is slight variation of BTE because of the occurrence of oxygen buffer of ZnO which lowers the oxygen requirement for more complete combustion process and therefore lower A/F ratio for ZnO addition with biodiesel(58). Nanoparticles help to split the hydrogen atom from water and which could have participated in the combustion process along with improving the rate of heat conduction, which lowers BTE (59, 60)

For the biodiesel and ethanol blend there is an increase of 5% as compared to diesel which is the baseline reading. The boiling point of ethanol is lower than diesel, the spray with blended fuels is improved which results in more complete combustion leading to enhancement of the combustion efficiency (61). Due to much improved and faster diffusive phase (as a result of increase in oxygen

amount of the fuel) which is backed by HRR of the blends occurring at almost the same location there is increase of BTE(57).Based on these explanations, BTE is increased as reported in (62-64).
In Fig.3. it is seen that there is a decrease of BTE by 3% for Zinc Oxide blend and 4% for ethanol blend when compared to diesel. For EGR to work there has to be a pressure diffrence between the inlet and exhaust manifolds to make sure the exhaust gases reach the inlet manifold and partially replace te air used for combustion. This is achieved by throttling the air of the inlet flow which adds extra load on the engine because it rises the pumping work. Thus for the same output more work has to be done thereby decreasing the thermal efficiency. This is offset by pumping more fuel but increases the bsfc when EGR is applied.(65)

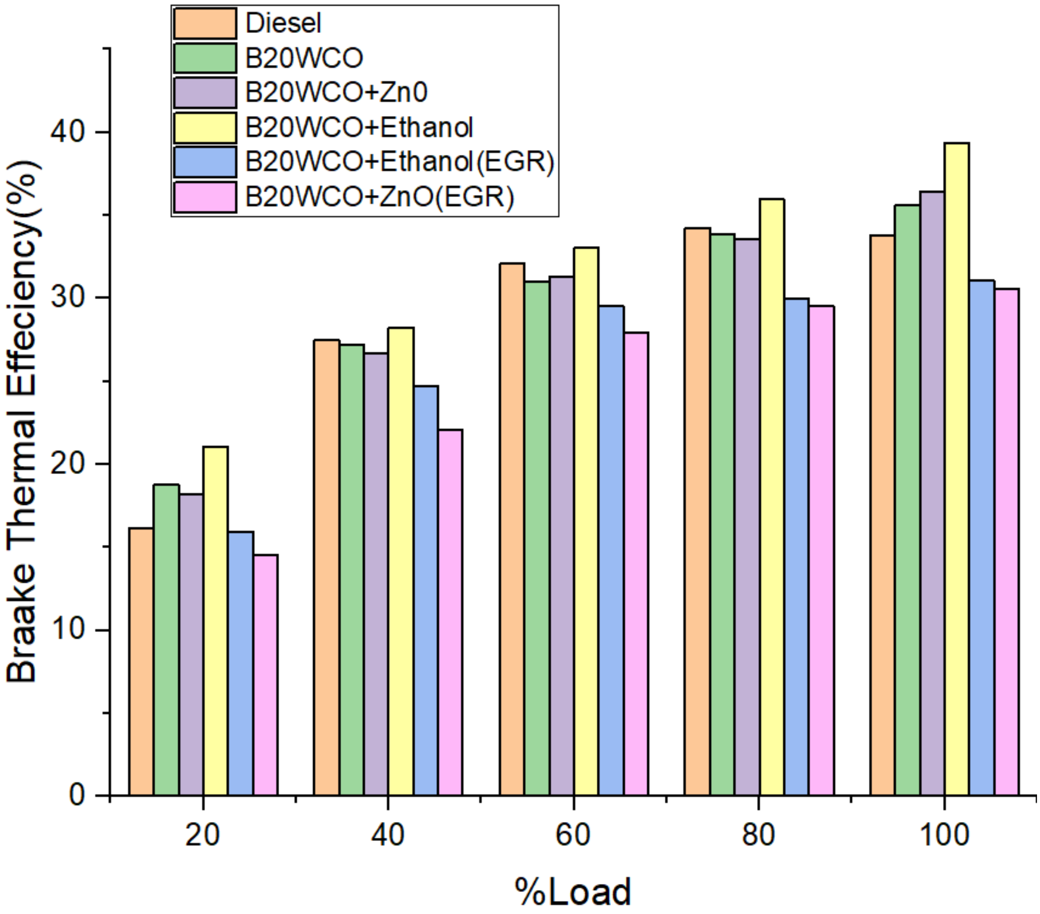

Fig.3. Break Thermal Efficiency vs % Load

3.2. Combustion parameter

3.2.1. P- θ

Fig.4. shows the variation of Pressure with Crank Angle, at full load the peak pressure value of is 7% lesser for the B20 blend of biodiesel and 9% lower for the biodiesel and Zinc oxide blend when compared to diesel. The peak in-cylinder is lesser for biodiesel as a consequence of high viscosity (75). When the injection pressure is increased, ignition delay decreases and better atomization of fuel takes place (76). This leads to a smaller accumulation of the fuel in the first phase and results in a decrease of the peak pressure as peak pressure in the cylinder is associated to the quantity of prepared fuel in the first phase .Zinc oxide improves the ignition which causes accelerated combustion and as a result leads to enhanced catalytic activity (77, 78).
For the ethanol additive there is decrease in peak pressure of 13%, mainly because of delay in combustion due to ethanol which shifts the location where the peak pressure of the cylinder occurs and gives rise to something called ignition delay (79,80).The reason why ignition delay is important is because it provides more accumulation of the fuel in the combustion chamber thereby knocking will occur resulting in pure combustion will occur as compared to no ignition delay or low ignition delay where incomplete combustion occurs. Another point to be noted is that as the load increases the diffrence in peak pressures between Diesel and other fuels with additives reduces which is very promising because it reduces the peak pressure diffrence between the Biodiesel and actual diesel.
Also peak pressure in the cylinder is directly correlated to the quantity of accumulated fuel present with in the first phase and as pressure increases, the delay reduces because of better atomization of the fuel which in turn leads to lesser buildup of fuel in first phase causing decrease of peak pressure. When EGR is applied, there is decrease in peak pressure for the blends due to the different composition which EGR introduces mainly Carbon Dioxide. And this subsequently increases as load increases. (65)

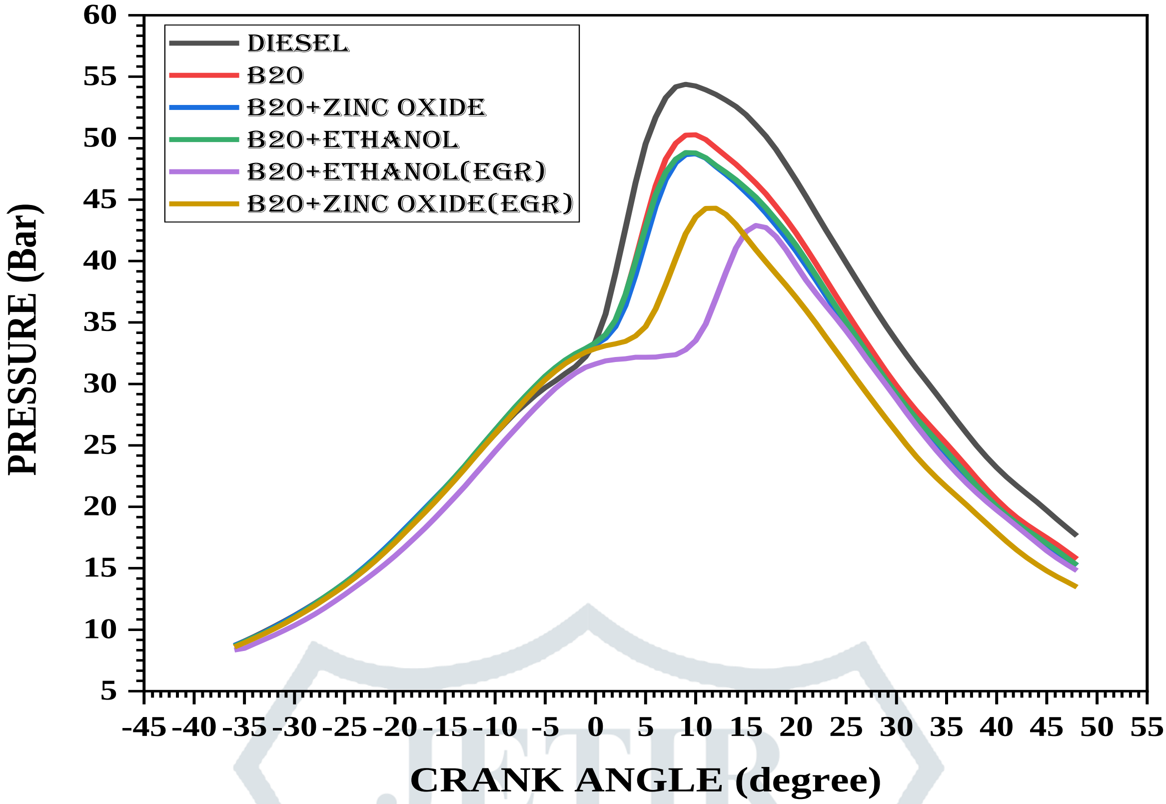

Fig.4. Variation of Pressure with Crank Angle

3.2.2. HRR (Heat Release Rate)

From Fig.5. it can be seen that the Maximum Heat Release Rate is 7% lower for B20 blend and 9% lower for the nanoparticle blended biodiesel B20 blend. It is because of lesser end temperature of combustion due to lesser calorific value of the blends (16). The greater cetane number and improved evaporation rate and A-F mixture of the blends there is shorter ignition delay (79) leading to lesser HRR. Also the better surface area/ volume ratio and upgraded ignition properties of nanoparticles cause better combustion of the blends compared diesel (58,74) leading to lower HRR.

For ethanol a decrease of 12% is noticed which may be owing to the cooling effect instigated by fuel vaporization and heat losses from the engine cylinder walls (81).Another point to note that with Biodiesel the Calorific value is poorer than diesel which will result in lower HRR.

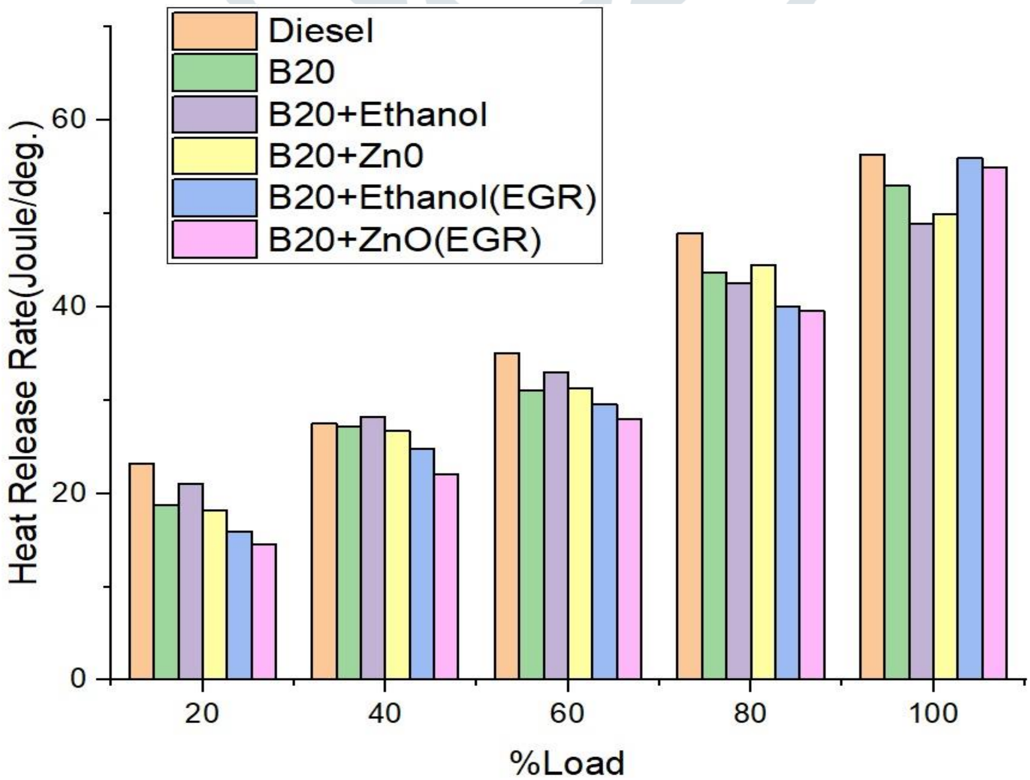

Fig. 5. Variation of Heat Release Rate with Load

3.3. Emissions parameter

3.3.1. NO_x emission

The NOx emissons for B20 blend of biodiesel is 15% lower than that of diesel due to the poorer iodine number of WCO which is around 59 which warranted the presence of the extra saturated fatty acids inB20 (82-87). The cetane number of biodiesel is superior compared to diesel due to the longer chains fatty acids and higher degrees of saturation (lower iodine number) which leads to lower NOx emission (88-90).

For the nanoparticle blend of biodiesel there is a decrease of 16% of NOx emissons when compared to diesel. Zinc Oxide increases the average temperature of the combustion chamber(due to improved Calorific value) which leads to greater oxygen in the blend to react leading to lower NOx emissions (16) ZnO absorbs oxygen for the reduction of NOx(91). Shorter ignition delay leads to better fuel-air mixing to cause an oxygen deficit for NOx leading to decrease of NOx emissions. NOx is reduced with the addition of ZnO being thermally stable which leads to reduction of nitrogen oxide

From Fig. 6. it can be seen that there is a decrease of 12% of the NOx emissons when compared to diesel. The decrease in NOx emissons for the ethanol blend is because of the peak in-cylinder pressure is slightly lower than those of the diesel and it mainly governed by the combustion rate in the first stage, which is influenced by the fuel participating in the premixed combustion phase (92). Since fuel injectors operates on gravimetric basis means a lesser mass of fuel will be injected which is less likely to promote NOx emissions as it is expected to lower the fuel to air ratio and reduction the local gas temperatures(93)

When EGR is applied there is a decrease in NOx emissons by 19% for ethanol blend and 21% for Zinc Oxide blend as EGR includes replacing the air used for combustion by CO2 and H20 vapor which has higher specific heat capacity than the main components of air which is oxygen and nitrogen leading to lower gas temperatures. Decrease in oxygen content due to it being replaced in EGR also leads to lower flame temperature and thereby reducing NOx emissons as formation of NOx is a highly temperature dependent phenomenon.(65)

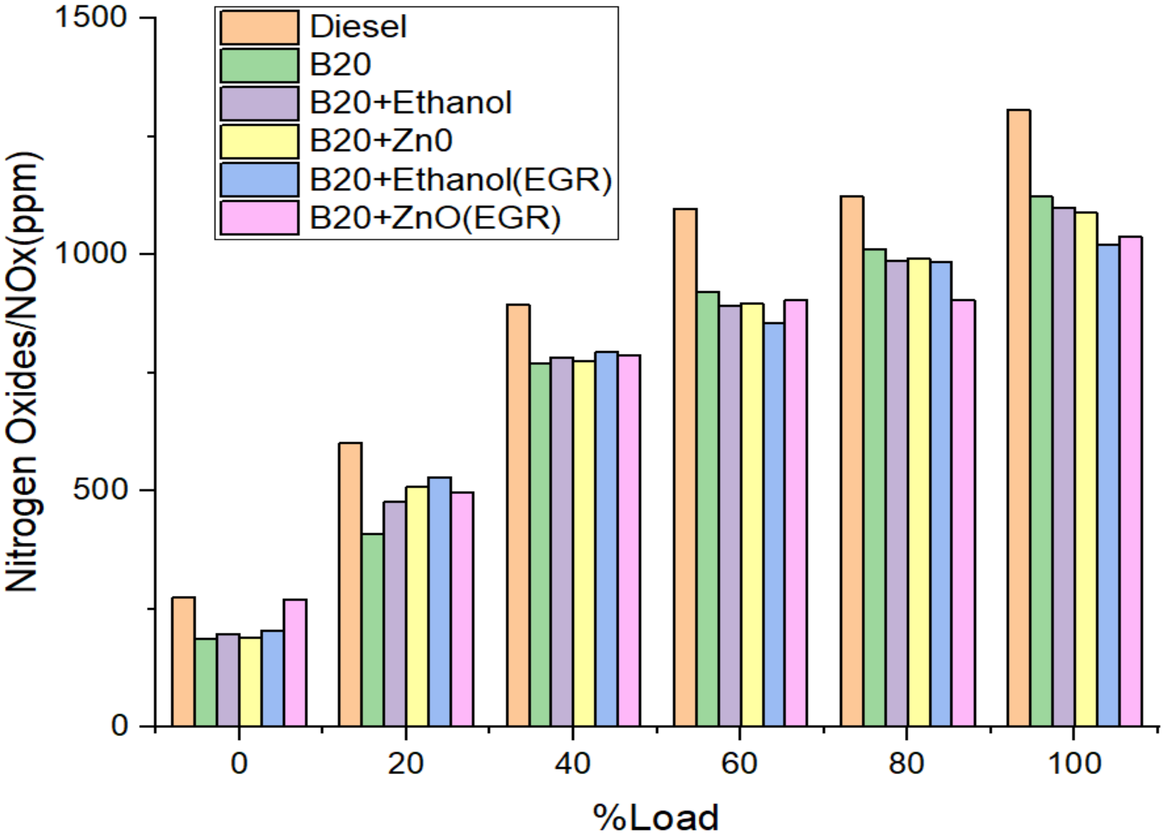

Fig. 6. Nitrous Oxide vs % Load

3.3.2. CO emission

Fig.7. shows the variation of Carbon Monoxide with Load and at full load there is a decrease of 29% of the CO emissons when compared to diesel. Presence of ignition delay as explained earlier maybe be detrimental to exhaust emissons, because it determines the quantity of the fuel burnt and increasing the burned fuel quantity in the premixed phase decreases CO emission. Zinc Oxide increases the average temperature of the combustion chamber(due to improved Calorific value) which leads to greater oxygen in the blend to react resulting in lower CO(16).ZnO also acts as an oxygen donating catalyst, and provides oxygen for the oxidation of CO(66) The decrease in CO emissons is also because by increasing the concentration of additives because of enrichment of oxygen owing to ZnO and biodiesel addition, increases the air-fuel ratio in the fuel rich regions which leads to better premixed combustion resulting in better complete.

The decrease in CO Emissons for ethanol blended fuel because by increasing the concentration of additives because of enrichment of oxygen owing to the ethanol and biodiesel addition, increases the air-fuel ratio in the fuel rich regions which leads to better premixed combustion resulting in better complete combustion by releasing CO2 gas instead of CO gas (94).

From Fig .7. it can be seen Carbon Monoxide emissons drop by 27% for the ethanol blended biodiesel. Cetane number reduction is a major drawback of ethanol though this is mostly counterbalanced by addition of biodiesel, there still is a reduction of it as shown in the fuel properties. Added to that the, drop in cetane number is also partially due to incomplete combustion of the ethanol-air mixture. This reduction of cetane number leads to lower CO.Enrichment of oxygen is another major factor, when the biodiesel is added as afore mentioned it is rich in oxygen, this increase in oxygen content leads to to carbon molecules being burned and combusted and thus releases C02 rather than the poisonous CO.(33)
When EGR is applied, Carbon Monoxide tends to slightly increase because of the lower oxygen which is available for combustion which results in rich air-fuel mixtures at different regions in the combustion chamber

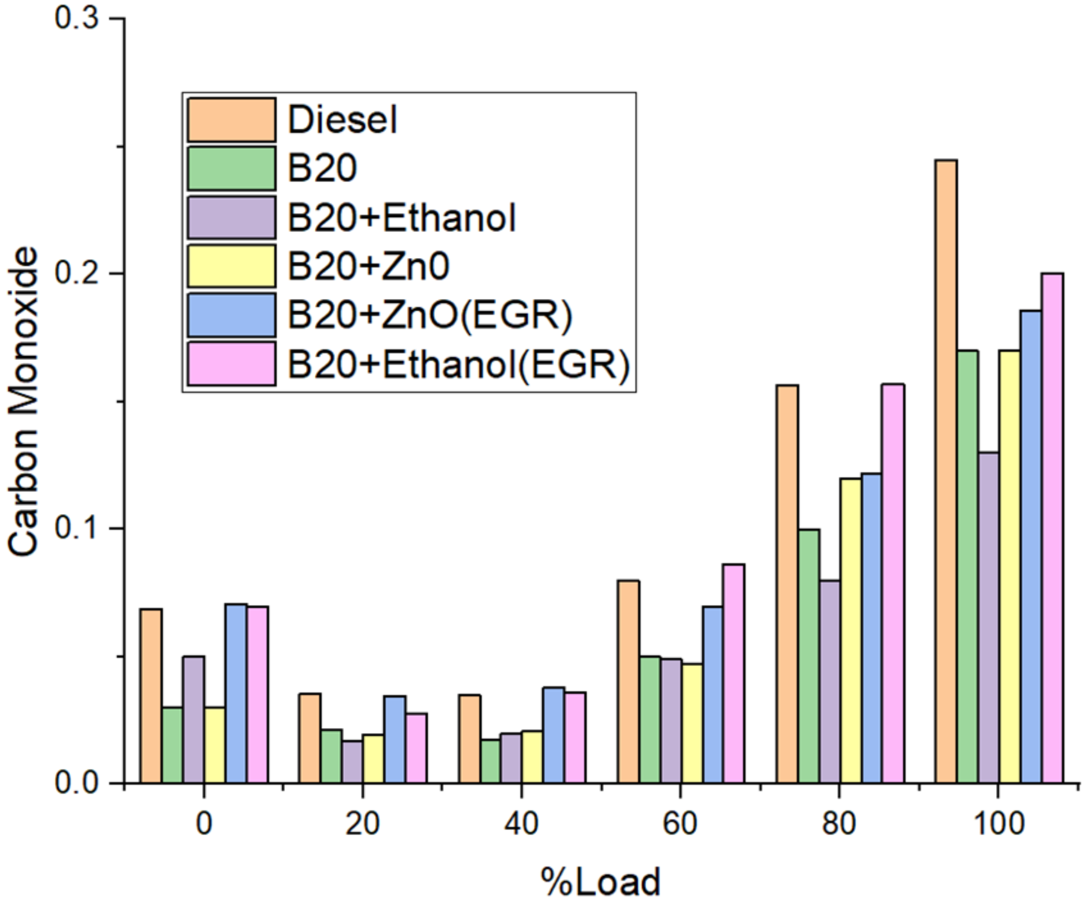

Fig.7, Variation of Carbon Monoxide with Load

3.3.3. HC emission

Fig.8. shows the variation of Hydrocarbon emissons with Load and at full load the HC emissions reduce by 16% for the Zinc Oxide blended fuel. The presence of nano additives acts as a binder and evades the undesirable fuel buildup and crevice area penetration thus decreasing the HC emissions . The nanoparticle acts as oxygen buffer and supplies additional oxygen which aids formation of stoichiometric mixture. From the figure it can be seen that ZnO is more effective in reducing Hydrocarbon emission at higher loads. HC emission drops becasuse of higher oxygen quantity of the blends which leads to improved overall combustion and higher cetane number which is provided by ZnO which enhances the combustion leading to lower hydrocarbon emissons
For the ethanol blend at full load HC emissons reduce by 19%.The reduction is due to the higher oxygen quantity of the blends which leads to improved overall combustion and higher cetane number which is provided by ethanol and biodiesel enhances the combustion leading to lower hydrocarbon emissons. In addition to this, the increase of oxygen molecules in the blends increases the oxidation post combustion as well in the combustion chamber (95)
There is a reduction by 22% for biodiesel at full load. Lower excess oxygen content results in improper combustion. But this deficit in oxygen is countermanded when B20 is added because B20 has molecular oxygen which decreases the oxygen necessary for combustion resulting in lower HC emissons (96). Biodiesel has greater oxygen content, which can accomplish improved combustion and lessen the HC emissions (97). The occurrence of oxygen in the blends increases the post flame oxidation process of UBHCs (Unburnt hydrocarbons) in the combustion chamber.

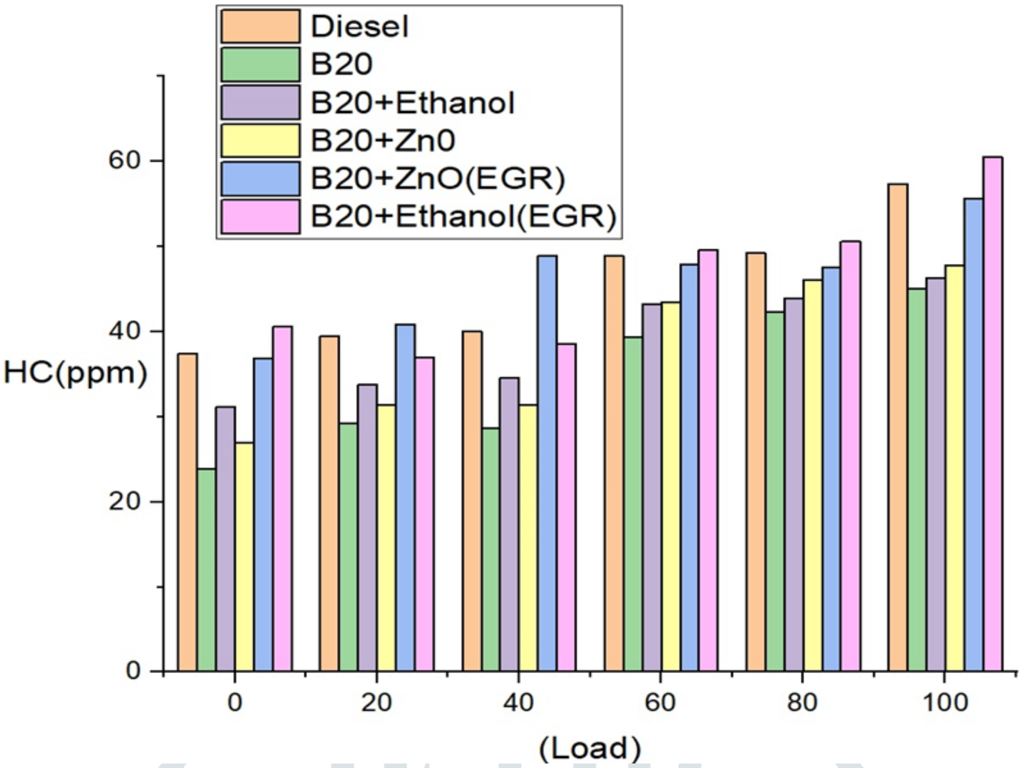

Fig.8. Hydrocarbon Emissions vs % Load

3.3.4. Smoke Opacity

Fig. 9. shows the variation of Smoke Opacity with Load, at 100% load for biodiesel there is a reduction of 9% and for biodiesel and zinc oxide blend there is a reduction of 5% when compared to the baseline reading of diesel. This is due to the advanced surface area -to - volume ratio of ZnO and greater cetane number causing complete combustion. Higher oxygen content in the blend enhances combustion and results in lowering of smoke emissions. (98) Also due to improved Sulphur and oxygen content of the nanoparticle blended fuel there is reduction of Smoke opacity.(16) Reduction of smoke opacity is because of the bonded oxygen which is higher in biodiesel compared to diesel that tends to reduce the soot formation (90,100)

For ethanol blended biodiesel there is a reduction of 7%.The main reason for the increased formation of soot is long injection period which results in a very fuel-rich core, but since an oxygenator-ethanol is used it oxidizes the fuel rich zones and also subdues the formation of soot in combustion chamber (101)Another reason for reduction of smoke opacity is bonded oxygen tends to reduce the soot formation and with ethanol being added to Biodiesel the amount of bonded oxygen increases which results in lower smoke opacity.(102)Not to forget decline of aromatic compounds(which are considered soot precursors) because ethanol does not provide the preliminary radicals which are required for development of aromatic rings (103). in the biodiesel+ ethanol fuel ,and also the configuration of soot from biodiesel is different from that of diesel which may favor oxidation leading to lower smoke opacity

It is seen that smoke opacity decreases as the load increases and at full load it decreases by 13% for ethanol blended biodiesel and 5% for Zinc oxide blended biodiesel. The main reasons why smoke opacity decreases in EGR is because of drop in the available oxygen level in the combustion chamber which is unfavorable for development of Soot. Also this reduction in oxygen causes decline of the flame temperature which again is negative for soot formation(104).Another reason for reduction of smoke opacity is bonded oxygen tends to reduce the soot formation and with ethanol being added to Biodiesel the amount of bonded oxygen increases which results in lower smoke opacity.(45)Not to forget decline of aromatic compounds(which are considered soot precursors) because ethanol does not provide the preliminary radicals which are required for development of aromatic rings . in the biodiesel and ethanol fuel ,and also the configuration of soot from biodiesel is different from that of diesel which may favor oxidation leading to lower smoke opacity (105).

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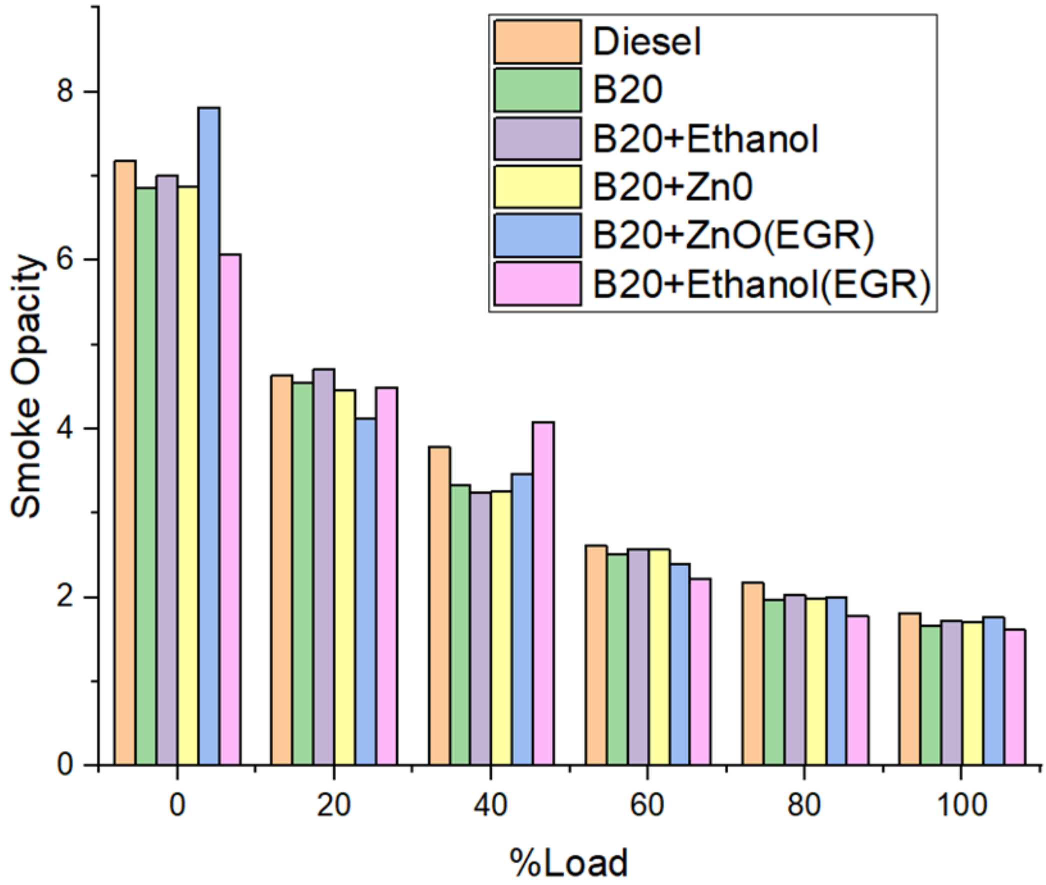

Fig.9. Smoke Opacity vs % Load

IV. CONCLUSION

The following are the conclusions drawn from the experimental results

1. Brake Thermal efficiency is slightly improved by the addition of Zinc Oxide nanoparticle, and with the oxygenator like ethanol the BTE has improved by 5%.When EGR is applied BTE slightly decreases, but this decrease of BTE is marginal (around 3% decrease)
2. Brake Specific Fuel Consumption decreases by 7% with the addition of Biodiesel to diesel, and 8% for Zinc Oxide additive. When ethanol is added to the biodiesel blend there is a similar decrease of BSFC when compared to the metal oxide additive. For EGR the decrease is slightly higher at 12%.
3. For combustion, the P- θ and Heat Release Rate (HRR) diagrams show that there is slight decrease in combustion but this is overcome partially with the use of Exhaust Gas Recirculation.
4. The unburnt hydrocarbons(UBHC) and Carbon Monoxide(CO) both decrease by about 20% for the additives and by about 25% when EGR is applied which is very promising trend.
5. Smoke Opacity/Particulate Matter decreases by about 9% for biodiesel and 5% for metal oxide additive. When Ethanol is applied to the blend, this reduction is slightly higher at 7% which shows reduction of emissions. EGR when applied to the blends decreases the UBHC and CO emissions by 15%.
6. Nitrogen Oxides/NOx reduces by 15% for the biodiesel blend due to inferior iodine number. For the Zinc Oxide nanoparticle additive, there is a decrease of16% due to improved combustion caused by higher volume to surface ratio. The oxygenator additive ethanol decreases the NOx emissions by 12 % because of cooling effect caused by the lower calorific value. MOREOVER, when EGR is applied, there is a decrease of about 20% due to lack of oxygen available for NOx formation

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