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Experimental Investigation on Influence of Additives on Emissions, Combustion and Performance of Diesel Engine along with EGR fueled with Waste Cooking Oil derived Biodiesel

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ABSTRACT: The Indian Government has recently mandated the blending of biodiesel with diesel. Indian Oil Cooperation, India's largest oil retailer, has started an initiative to blend Biodiesel produced from Waste Cooking Oil, with Diesel. The usage of biodiesel in a diesel engine reduces emissions by a significant amount, but it negatively impacts its performance and combustion related parameters. To overcome these shortcomings, additives are used along with the biodiesel blend to enhance the properties. In this paper two such additives are studied-Zinc Oxide nanoparticles and Ethanol are used along with the biodiesel blend to enhance the properties. In the present experimentation a TV2 diesel engine made by Kirloskar has been fueled with waste cooking oil methyl ester (WCOME). Trails have been done with varying loads from 0-100% with considering diesel as the standard reading. Totally 4 blends have been used in the TV2 engine- Diesel, B20 biodiesel (20% WCOME +80% Diesel), B20 Biodiesel+15% Ethanol (Oxygenator additive) and B20 Biodiesel+80ppm of Zinc Oxide (Nano metal additive) and Exhaust Gas Recirculation has been applied to all the Biodiesel blends. For easier comparison, all the results have been plotted on graphs. The performance parameters of the engine taken into consideration are Brake Thermal Efficiency (BTE) and Brake Specific Fuel Consumption (BSFC). From the results, it can be concluded that both BTE and BSFC improved by approximately 7% due to the presence of the additives. For evaluating the combustion characteristics of the engine, Heat Release Rate and Cylinder Pressure v/s Crank Angle behavior of the engine have been studied. And for better understanding how the blends and the additive affect emissions from the engine, 4 parameters are studied- Carbon Monoxide (CO), Smoke Opacity, Nitrogen Oxides(NOx) and Unburnt Hydrocarbon Emissions (UBHC).UBHC and CO both decrease by about 20% for the additives and by about 25% when EGR is applied, which is very promising trend. NOx reduced by 15% due to the additives. The results of all 3 parameters of the engine are very promising for both Zinc Oxide (nanoparticle additive) and Ethanol (Oxygenator additive).

Keywords: Waste Cooking Oil, Combustion, Emissions, Ethanol, EGR, Nanoparticle, Performance, Biodiesel.

Abbreviations: B20WCO, 20% Waste Cooking Oil+80%Diesel; WCOME, Waste Cooking Oil Methyl Ester, NOx, Nitrogen Oxides ; UBHC, Unburnt Hydrocarbon Emissions; EGR, Exhaust Gas Recirculation; PPM, Parts per Million.

I. INTRODUCTION

Metallic additives has been employed as additives since the early 2000s but recently their usage has increased due to their availability in the form of nanoparticles. Nanoparticles act as a catalytic agent and provides several benefits like improvement of combustion enthalpy, shorter ignition delays and better combustion of the fuel mixture resulting in lower harmful emissions [2]. Surface area to volume ratio is a very important parameter of a nanoparticle because the higher this ratio is, the quicker the nanoparticle facilitates oxidation, this is possible due to the additional surface being available. The reactivity, electrical properties and strength of the nanoparticle can be improved by varying the surface area to volume ratio. Nano additives reduce harmful emissions and fuel consumption because of the hydroxyl ions developed due to the reaction of metal with water and thus there is improvement of soot oxidation and better combustion of hydrocarbon in the soot, thereby reducing the temperature of oxidation [4, 5]. Furthermore, there are several active surfaces on nanoparticles which improves the rate of dispersion, and also avoids fuel injector clogging [6, 7].

One shortcoming of biodiesel is that it has high kinematic viscosity; this can be overcome by blending it with oxygenators [8]. Oxygenators are oxygen containing chemical compounds which are vital additives for diesel engine as the use of it gives oxygenated fuel. The property of a good oxygenator is "it should capable of mixing in any ratio without separation of its two phases with various fuels" [9]. Oxygenators make the combustion process faster as a result of the increased speed of propagation of the laminar flame, which improves the thermal efficiency and also, reduces the amount of harmful chemicals released into the atmosphere by enabling the better burning of fuel in the engine [10]. With the right molecular structure and oxygen amount in the fuel, oxygenators can decrease the ignition temperature of particulates. Among oxygenators, alcohol is a particularly good option and amongst the alcohols, ethanol is a suitable additive [11]. Ethanol is not carcinogenic and is not flammable like methanol when used as a motor fuel. The earliest employment of ethanol in compression ignition engines started in South Africa in the early 1980s and was carried forward in the United States and Germany during the late 1980s. Ethanol can be considered a renewable fuel because it can be distilled and fermented from biomasses. Ethanol is a good oxygenator for biodiesel because it tends to decrease kinematic viscosity of biodiesel due to its short- reactive carbon chains, and higher viscosity is one of the drawbacks of biodiesel as mentioned earlier. Ethanol also maximizes superficial contact by lowering the surface tension between oil and water [12]. The drawbacks of ethanol are its lower calorific value and cetane number. It is also very corrosive to the walls of the fuel tank. The lower cetane number is partially overcome with the addition of biodiesel, as it has superior cetane number in comparison with diesel. Ethanol possesses lower viscosity, self-ignition temperature and lower flash point than biodiesel. The reduction in lubricity caused when ethanol is introduced in the blend can create potential wear problems in modern fuel pump which employ a fuel-based lubrication [13, 14]. The downsides of using biodiesel and ethanol is that the addition affects properties like stability and volatility. Phase separation occurs at relatively low temperatures when the interfacial film is broken because of increased pressure at lower temperatures. This problem can be solved in multiple ways- one possible solution is by blending an emulsifier which lowers the surface tension of the blend by suspending ethanol droplets in diesel fuel; another solution is mixing with a co-solvent which increases the blend's solvency. Solubility of ethanol also depends on the "hydrocarbon composition and wax content of the base diesel and biodiesel" [15-17].

Increase in demand of ethanol derived from natural sources in India will reduce pollution and toughen India's resolve towards accomplishing 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. Blending Ethanol with fuel will reduce India's energy import dependency helping the country save $1 billion in crude oil imports in the coming years and make India self-reliant, the idea of which the Government of India is trying to push. In view 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.

India is the third largest importer of oil in the world, importing more than 75% of its oil requirements and close to 20% of its natural gas requirements, thus by growing ethanol production India can definitely save some forex reserves. The production of ethanol worldwide has increased by nearly 200%, from nearly 40 billion liters in 2007 to more than 85billion liters in 2013 and is anticipated to grow by 500% by the end of 2025.

Exhaust Gas Recirculation (EGR) has widely been acknowledged to be the most feasible method to reduce NOx emissions with great effect. In EGR, a ratio of the exhaust gas is recycled to the engine which reduces the oxygen available for the harmful emissions and thus leading to reduction of the harmful emissions. Hot EGR is a widely used technique in EGR which basically keeps the exhaust temperature inflated which diminishes NOx, Smoke Opacity and HC. The "specific heat capacity of the fuel mixture is raised" by recycling the exhaust gases into the intake air of the engine which also reduces oxygen concentration of the intake mixture [19]. Thus there is significant reduction of harmful emission because of these two factors. Another point to note is that EGR doesn't not affect the fuel efficiency [19].

Waste Cooking Oil (WCO) is a promising feedstock and numerous biodiesel production facilities are presently utilizing it as it is 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 [20, 21]. Using this discarded WCO for production of biodiesel is a possible solution to properly dispose WCO and this would also decrease the reliance on diesel [22]. Collation of WCO from diverse sources can therefore produce a heterogeneous feedstock stream, and standardizing the characteristics of WCO is therefore inherently difficult. Nowadays suppliers have to pay a higher amount to procure WCO compared to uncooked or virgin oil because WCO is considered safe for consumption by animals in most parts of the world [23]. Between 2010 and 2017, the utilization of WCO has increased progressively, resulting in a 350% upsurge in its use in the European Union, rising from 670,000 tonnes to 2.45 million tonnes [24]. A major stimulus for increased WCO Biodiesel consumption is the fact that it reduces emissions which are one of the shortcoming of diesel engines. It does this by increasing the oxygen amount in the fuel which produces better combustion and is extremely useful for curtailing NOx formation. Consumption of biodiesel has been on the rise especially in the European Union because it accounts for double (2x) carbon credits and also it reduces dependency on fossil fuels and helps shrink greenhouse gas effect, and this usage is also motivated to comply with the targets of the European Parliament. WCO can be utilized in a compression ignition engine without penalizing the efficiency and also there is significant diminution of Smoke opacity, CO, HC and NOx emissions [25-28].

Likos *et al.,* [29] observed that the thermal efficiency of the ethanol–diesel blend was similar to that of neat diesel fuel and at heavy loads HC and CO were reduced with a small increase in NOx emissions. The study conducted by Krishna *et al.,* [30] demonstrated that Biodiesel Diesel Ethanol blends have fuel properties as well as engine performance and emission characteristic identical with diesel. The reason why ethanol is studied in this paper is because there have been no prior studies of using ethanol as an oxygenated additive along with Waste Cooking Oil Methyl Ester. The intention behind using Zinc Oxide as the nanoparticle additive is because studies done using ZnO nanoparticle [31-37] have something lacking in them- either the amount of Zinc Oxide used is a lot which leads to significant accumulation of nanoparticles in the liver and can result in cellular injury [38]. And there has not been prior studies where all 3 parameters (Performance, Emissions and Combustion characteristics) have been performed with taking Zinc Oxide and Waste cooking oil along with EGR.

In this present work, WCO has been used as biodiesel along with Zinc Oxide nanoparticle and ethanol. EGR has been employed for further reduction of emission.

II. MATERIALS AND METHODS

Transesterification: There were totally 4 blends used- pure Diesel, 20%Biodiesel+80%Diesel (B20), B20+80 ppm Zinc Oxide and B20+15% Ethanol. The biodiesel was obtained from the Transesterification process. Transesterification has been used to convert WCO which is predominantly triglycerides to glycerol, with methanol being the choice of alcohol and Potassium Hydroxide (KOH) being the catalyst as shown in Fig. 1. The steps carried out in transesterification is similar to Lobo et al. [39].The properties of the fuels used in experimentation is given in Table 1.

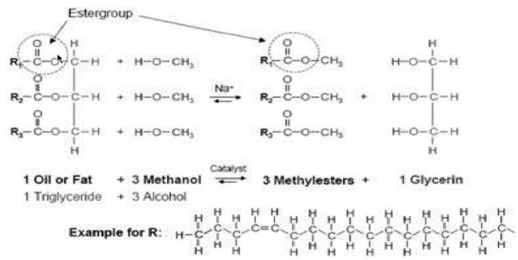

Fig. 1. Transesterification of Oil.

For experimentation, 80ppm ZnO and ethanol is blended separately with WCOME and this biofuel is used in a Kirloskar TV2 engine which has been loaded from 0-100% for investigation and all the values were plotted on a graph for easy comparison. In total, four blends are used for experimentation which are Diesel, B20 WCOME (20% WCOME + 80% Diesel), B20 WCOME + 80 ppm ZnO and B20 WCOME+15% Ethanol.

Error analysis and uncertainty: Error Analysis and Uncertainty is done for this experimentation similar to Lobo *et al.* [39] the experiment uncertainty was 1.765%

Table 1: Properties of Fuels.

Properties	Diesel	WCO (Waste Cooking Oil)	WCOME (WCO Methyl Ester)	B20WCOME (20%WCOME + 80% Diesel)	Ethanol	B20WCOME+ 15%Ethanol
Kinematic Viscosity (40°C)	3.05	43	5.83	4.01	1.2	3.765
Heat Value(MK/Kg)	44.5	29	38	42.9	27.9	36.8
Density (Kg/m^3)	830	914	887	842	790	828.75
Flash Point °C	61	308	150	97	14	79
Cetane Number	41	54	52	49.18	110 (Octane Number)	48
Iodine Number	6	125	59	17.42	-	57

III. RESULTS AND DISCUSSION

Experimentation has been conducted and graphs have been tabulated and plotted. The different characteristics which was measured are, Combustion- Heat Release Rate (HRR) and (P- θ), Emissions: Carbon Monoxide (CO), Nitrogen Oxides (NOx), Smoke Opacity, and Hydrocarbons (HC), and Performance: Brake Specific Fuel Consumption (BSFC) and Brake Thermal Efficiency (BTE)

A. Performance Characteristics

The performance characteristics considered in this paper are Brake Thermal Efficiency and Brake Specific Fuel Consumption.

Brake Thermal Efficiency (BTE): Fig. 2 illustrates the fluctuation of 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 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 [40]. By the addition of ZnO there is slight variation of BTE because of the occurrence of oxygen buffer of ZnO which lowers the amount of oxygen required for better combustion [41]. Nanoparticles of Zinc Oxide help to split the H_2 from H_2O and which could have participated in the combustion process along with improving the rate of heat conduction which lowers BTE [42, 43].

For the biodiesel and ethanol blend there is an increase of BTE by 5% as compared to diesel which is the baseline reading. Since the boiling point of diesel is superior to that of ethanol, the spray properties of the ethanol blended fuel is enhanced, producing better combustion leading to enhancement of the combustion efficiency [44].

Due to much improved and faster diffusive phase as a result of rise in the amount of oxygen in the fuel there is increase of BTE [40].

Based on these explanations, BTE is increased for the blends and it is also backed by studies conducted by 45 & 46.

In Fig. 2 it is seen that there is a decrease of BTE by 3% for Zinc Oxide blend and 4% for ethanol additive. For EGR to work there has to be a pressure difference between the exhaust and inlet manifolds to make sure the exhaust gases reach the inlet manifold and partially replace the 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 [47].

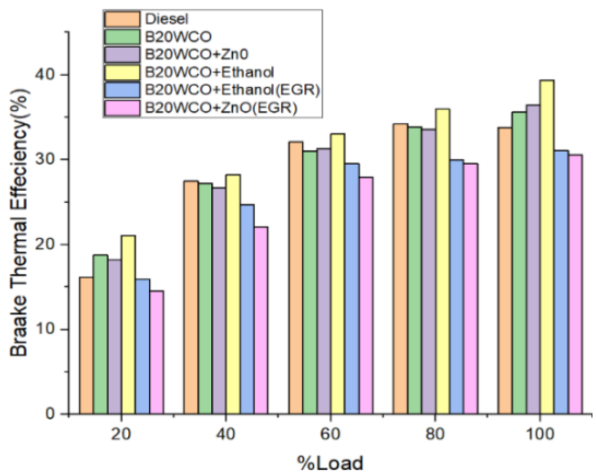

Fig. 2. Fluctuation of BTE with Load.

Brake Specific Fuel Consumption (BSFC). From Fig. 3, at 100% there is a decrease of BSFC by 7% when compared to diesel. The combustion is also improved by addition of an oxidizing agent and ZnO plays that role of an oxidizing agent when added to the blend, and because ZnO is an oxidizing agent it also improves the Air to Fuel ratio reducing the BSFC. One of the causes for reduction of BSFC can be better combustion caused by shorter delay of ignition as a result of addition of a nanoparticle like ZnO [48]. Employing an additive like Zinc Oxide increases the flash point properties and reduces the pour point of the blend, thereby reducing BSFC. The lower oxidation temperature caused by the catalyst effect of the ZnO nanoparticle directly causes the decline of BSFC [49-51]. 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- boiling point and self-ignition temperature. Ethanol has a higher self-ignition temperature than 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 inferior, it will evaporate before diesel and will back the progress of the combustion through the unburned blend spray thereby reducing consumption of excess fuel. Moreover, because of the inferior latent heat of ethanol, dissociation reactions could be anticipated, reducing the specific consumption of fuel [52]. Another reason is ethanol decreases the mass flow rate of the blend, because the density decreases as we increase the percentage of ethanol.

When EGR is applied to the blends, for the Zinc oxide the BSFC is increased of nearly 12% when compared to diesel and for ethanol it is 10%. By applying EGR the BSFC rises because of shifting the Fuel to Air ratio, which creates an oxygen deficit, dilution effect and the dwindling rate of burning, making constant state of combustion harder to attain [53, 54].

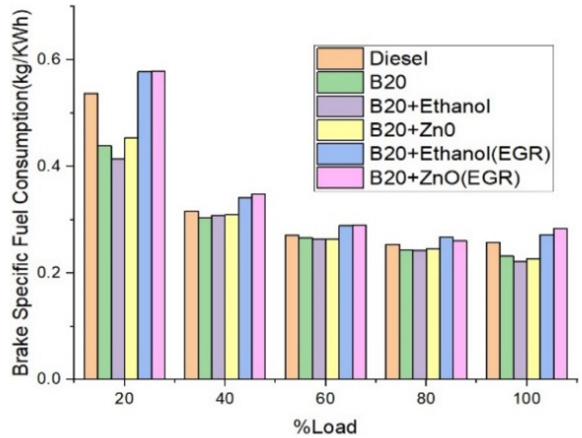

Fig. 3. Fluctuation of BSFC with Load.

B. Combustion Characteristics

Cylinder Pressure v/s Crank Angle (P- θ). Fig. 4 illustrates the fluctuation of Pressure with Crank Angle. At 100% load the value of maximum pressure is 7% lower for the B20 blend of biodiesel and 9% lower for the biodiesel and Zinc oxide blend in comparison with diesel. The peak in-cylinder is lesser for biodiesel as a consequence of high viscosity [2]. When there is increase of injection pressure, there is a decrease of ignition and better atomization of fuel takes place [55]. There is lesser buildup of the fuel in the first phase which causes decrease of the peak pressure as amount of prepared fuel in the first phase is associated with peak pressure in the cylinder. Enhancement of the catalytic property takes place as a result of ZnO because the addition of ZnO enhances the ignition and as an outcome of that is there is accelerated combustion [56, 57].

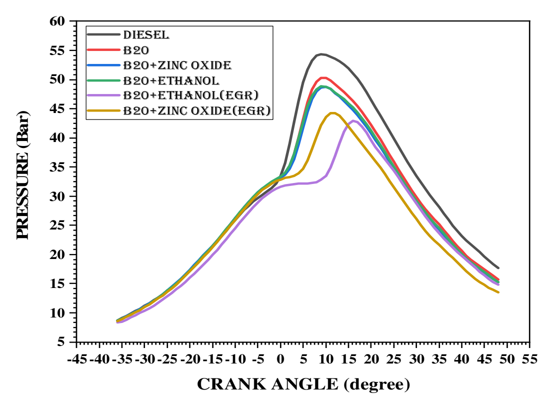

Fig. 4. Fluctuation of Pressure with Crank Angle.

For the ethanol blended fuel there is decrease in peak pressure of 13%, mainly because of delay in combustion due to the oxygenator which shifts the location where the peak pressure of the cylinder occurs and gives rise to something called ignition delay [58]. The reason why ignition delay is important is because it provides more accumulation of the fuel in the combustion chamber thereby slight knocking will occur resulting in better combustion 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 difference in peak pressures between Diesel and other blends with additives reduces which is very promising because it reduces the peak pressure difference between the Biodiesel and actual diesel.

Also, pressure in the cylinder is directly correlated to the amount of accumulated fuel present within the first phase and as pressure increases, the delay reduces because of improved 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 caused due to the different composition of the air (mainly CO_2) which the EGR system introduces. This subsequently increases as the load increases.

Heat Release Rate (HRR). The maximum HRR 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 blends having lower calorific value. The occurrence of greater cetane number, enhanced evaporation rate and superior A-F mixture of the blends causes shorter ignition delay leading to lesser HRR [58]. Also the better volume to surface area ratio and upgraded ignition properties of nanoparticles cause enhanced combustion of the blends compared diesel leading to lower HRR.

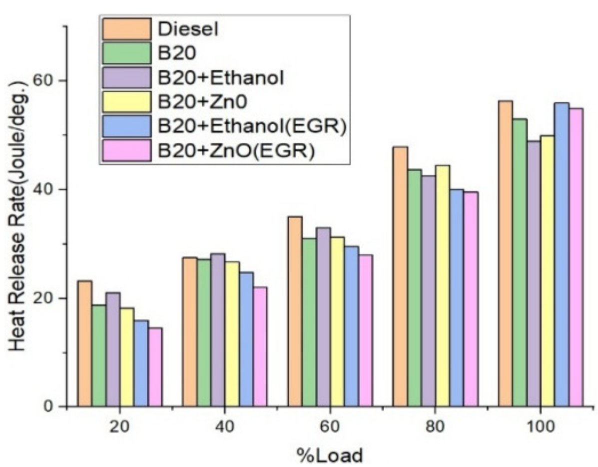

Fig. 5. Fluctuation of Heat Release Rate with Load.

C. Emissions Characteristics

Nitrogen Oxides (NOx). The NOx emissions for B20 blend of biodiesel is 15% lesser compared to diesel due to the poorer iodine number of WCO which is around 59-which is due to the existence of the extra saturated fatty acids in B20 [59, 60]. The cetane number of WCO is superior compared to diesel, due to the saturation degree being higher and longer chains fatty acids which leads to lower NOx emission [61, 62].

For the nanoparticle blend of biodiesel there is a decrease of 16% of NOx emissions when compared to diesel. One of the consequences of the blends having higher Calorific value is that the average temperature of combustion is increased leading to greater amount of oxygen to react and lowering the NOx emissions [63].

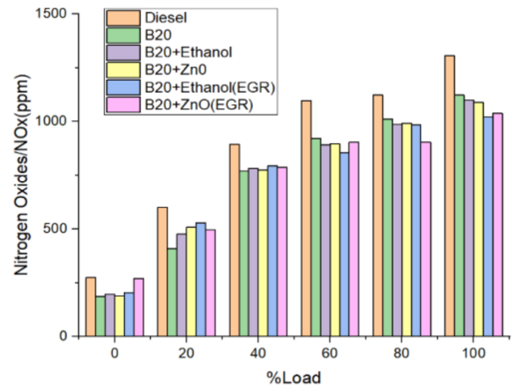

Fig. 6. Fluctuation of NOx with Load.

With employing thermally stable ZnO there is a decrease of NOx because ZnO introduces a shorter delay of ignition which results in better A/F ratio and creating an oxygen deficit in the chamber.

From Fig. 6 it can be seen that there is a reduction of 12% of the NOx emissions for the ethanol blend in comparison with diesel. The decrease in NOx emissions for the ethanol blend is because the cylinder pressure is slightly lower than that of diesel and it mainly governed by rate of combustion in the first stage, which is inclined by the amount of fuel participating in the premixed combustion phase [64]. Since fuel injectors operate on gravimetric basis, this means a lesser amount of fuel will be injected leading to lower emissions of NOx because of inferior A-F ratio and lower local gas temperature [65].When EGR is applied there is a decrease in NOx emissions by 19% for ethanol blend and 21% for Zinc Oxide blend as EGR includes replacing the air used for combustion by CO_2 and H_2O vapor which has higher specific heat capacity than the oxygen and nitrogen (which are the main components of air) leading to lower gas temperatures. Decrease in oxygen content of the air in the combustion chamber due to EGR also leads to inferior flame temperature and thereby reducing NOx emissions as formation of NOx is a highly temperature dependent phenomenon.

CO (Carbon Monoxide) Emissions. At full load there is a reduction of 29% of the CO emissions in comparison to diesel. CO emissions are decreased because greater quantity of fuel is being burnt during combustion and this is elucidated by the presence of ignition delay as depicted in the P-θ diagram. And because of the superior calorific value of the blends, there might be a reduction of CO emissions. Enrichment of oxygen is another major factor, because biodiesel is rich in oxygen, this increase in oxygen content leads to carbon molecules being burned and combusted and thus releases CO_2 rather than the poisonous CO.

The decrease in CO Emissions for ethanol blended fuel is caused by enhancement of oxygen content due to ethanol addition which increases the fuel air ratio in the fuel rich regions which leads to more complete combustion and as a result CO_2 gas released from the exhaust instead of poisonous CO gas [66].

From Fig. 7 it can be seen CO emissions 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, but there still is a reduction which can be seen in the fuel properties. 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 carbon molecules being burned and combusted and thus releases CO_2 rather than the poisonous CO. When EGR is applied, Carbon Monoxide tends to slightly increase because of the lower oxygen which is available for combustion which results in various regions of the chamber having rich A/F ratios.

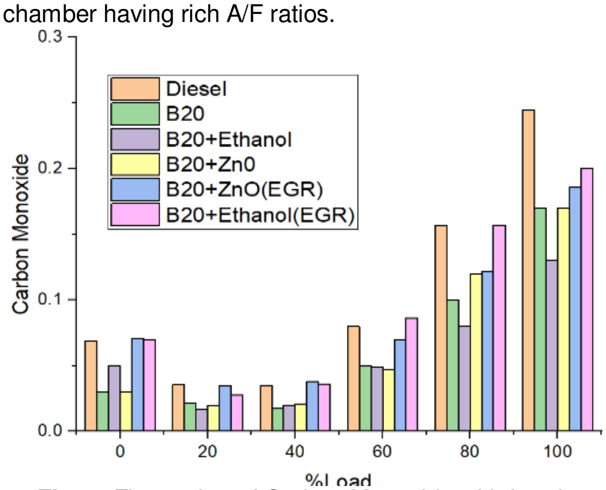

Fig. 7. Fluctuation of Carbon Monoxide with Load.

Hydrocarbon (HC) emissions. The Hydrocarbon emissions at full load reduces by 16% for the Zinc Oxide blended fuel. The ZnO nanoparticle supplies extra oxygen and acts as oxygen buffer which supports the creation of stoichiometric mixture. From Fig. 8 it is seen that nanoparticle is highly operative in tackling HC emissions at 80-100% loads possibly because of the supply of extra oxygen and also by ZnO acting as an oxygen buffer. HC emission drops because of higher O_2 quantity of the blends which causes improved overall combustion. For the ethanol blend at full load HC emissions reduce by 19%.

The drop is due to the greater 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 emissions. The rise of O_2 molecules in the blends rises the oxidation post combustion as well in the combustion chamber [67].

There is a reduction of HC emissions 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 emissions [68]. Biodiesel has greater oxygen content, which can accomplish improved combustion and lessen the HC emissions [69]. The post flame oxidation process of the UBHCs is enhanced because of more amount of oxygen being available during combustion.

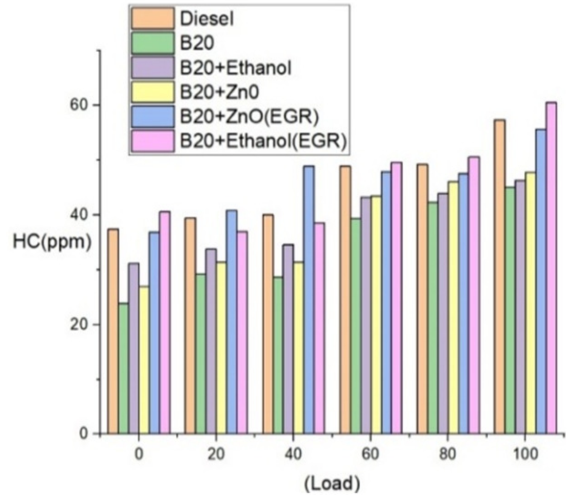

Fig. 8. Fluctuation of Hydrocarbon emissions with Load.

Smoke Opacity. Fig. 9 shows the fluctuation 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. There is reduction of Smoke Opacity because of the superior volume to surface area ratio of Zinc Oxide and also the superior cetane number of the biodiesel blend, so both these aspects result in better combustion. The decline of Smoke Opacity can be caused by the higher Sulphur and oxygen content in the blend [70]. Lessening of smoke opacity can also be because of the bonded oxygen which is higher in biodiesel compared to diesel that tends to reduce the soot formation [71, 72].

For ethanol blended biodiesel there is a reduction of 7%. When there is a long injection period, soot is formed and this results in a very fuel-rich core, but when ethanol is employed as an additive, it oxidizes the fuel rich zones and also subdues the formation of soot in combustion chamber [73]. 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 [74].

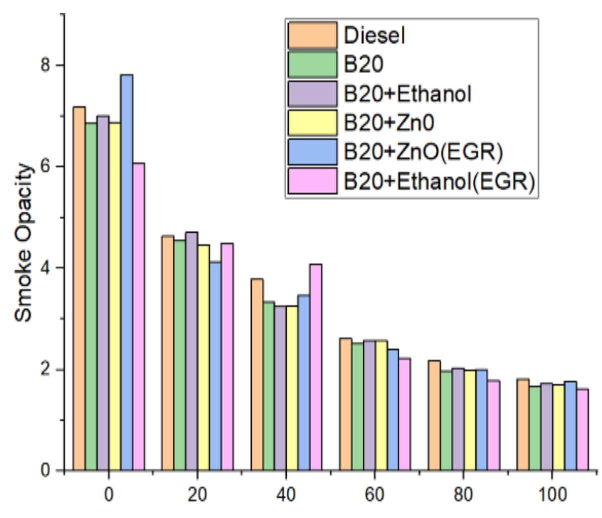

Fig. 9. Fluctuation of Smoke opacity with Load.

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+ ethanol blend, and also the configuration of soot from biodiesel is different from that of diesel which may favor oxidation leading to lower smoke opacity [76]. It is seen that smoke opacity decreases as the load rises, 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 content 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 [75]. 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.

IV. CONCLUSION

– BTE is slightly upgraded by the introduction of ZnO 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)
– BSFC decreases by 7% with the blending of Biodiesel to diesel, and 8% for Zinc Oxide additive. When ethanol is supplied 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%.
– For combustion, the P- θ and HRR diagrams show that there is slight decrease in combustion but this is overcome partially with the use of EGR.
– UBHC and CO both decrease by about 20% for the additives and by about 25% when EGR is applied which is very promising trend.
– 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%.
– 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. And when EGR is applied, there is a decrease of about 20% due to lack of oxygen available for NOx formation.
From the experimentation it presents a very clear case for the use of Waste cooking oil derived biodiesel and the additives which can be used along with it.

V. FUTURE SCOPE

Though there are a lot of advantages with the studied biodiesel and additives it is still important to understand that the goal hasn't been reached. The goal for the WCOME is to be derived from varied sources of waste cooking oil and not a single source since collection of a single source of cast-off oils requires a huge amount of investment and infrastructure. For ethanol additive, the scope for future is to optimize production from disposed biomass and more importantly search for methods wherein the use of microalgae can be employed to derive ethanol. Finally coming to the nanoparticle ZnO, there is a lot of future scope in this field because the research on nanoparticles is increasing exponentially and the potential of these particles is immense. Even though there are still multiple methods to fabricate it, they are not on a scale wherein it can readily be available to the masses at a low cost. Also there is the inherent problem of nanoparticles being extremely small and damaging the respiratory system of animals. The possible solution to this would be to research on a material which can trap these harmful particles. All things considered the future scope for the materials and methods use in this paper is immense.

Conflict of Interest. The authors declare that there is no conflict of interests regarding the publication of this paper.

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