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Experimental Investigations on CI Engine for Performance, and Emissions Fuelled with Stabilised Binary Diesel/ JME Blends Doped with Nano Metallic Oxide Additive Particles Using DEE and Non- Ionic Surfactants

N.S.C. Chaitanya[1], Y.V.V. Satyanarayana Murthy[2], M.R.S. Satyanarayana[1]

[1]*Mechanical Engineering Department. GITAM University, Visakhapatnam, India,*
[2]*Indian Maritime University, Chennai, India*

chaitanyanadimpalli@gmail.com, yvvsnmurthy@imu.ac.in, mmunukur@gitam.edu

ABSTRACT
Research with experimentation was carried out to assess the impact of the addition of nano-sized fuel-borne additives (Al_2O_3) to a tri-fuel mix consisting of pure diesel, biodiesel made from Jatropa methyl ester, , and diethyl ether (DEE). The combustion, performance, , and emission characteristics of this tri-fuel combination are studied in a compression-ignition engine having a single cylinder. DEE is widely recognized as an ignition improver owing to its higher cetane number , and also serves as a stabilizer for the suspended nanoparticles. The size of Al_2O_3 nanoparticles was fixed at 25nm, , and concentration is changed from 25ppm to 50ppm in binary diesel/ JME mix. Nanoparticles have a greater surface area/volume ratio, allowing for more efficient combustion , and better engine performance , and emissions. Surfactants Triton-X100 , and Brij58 were selected independently to suspend the nanoparticles in this fuel mix utilizing an ultrasonic liquid processor. The experiment findings indicate that tri-fuel mix with Al_2O_3 nanoparticles demonstrated 1.25 percent better brake thermal efficiency than neat diesel, decreased NOx emissions by 200ppm than plain diesel. It is also discovered that Brij58 exhibited superior performance compared to triton-X100 surfactant in the refuel mix.

Keywords: *Jatropa, Al_2O_3 Nanoparticles, DEE, Surfactants, NHRR, CHRR, NOx & Smoke.*

I. Introduction

The recent rise in the price of petroleum, together with concerns about air pollution , and the impact of global warming, has reignited global interest in developing nonpetroleum engine fuels. Many biodiesels have been tested over the years for their possible usage as an alternative fuel, many of them have been found to be suitable, , and research has been going on continuously to further enhance these biofuels by various additions to them for negating the negative impact of the biodiesels on the engine as well as the environment. In this research, we have added DEE to the biodiesel , and also Al_2O_3 nanoparticles. The impact of these biodiesel additions on the various characteristics related to performance, combustion characteristics as well as emission characteristics of a CI engine was studied. DEE is a substitute for vegetable oil/diesel in diesel engines.[1]. The dehydration of bio-ethanol, a renewable fuel, may result in the production of Jatropa oil. DEE has the autoignition temperature on the lower side , and is also highly volatile; because of these qualities, it is suggested for use as an additive for cold starting in diesel as well as gasoline engines [2].

DEE may be used as a fuel either in pure form or by mixing with diesel in CI engines. The autoignition temperature of DEE is lower in comparison to that of diesel. DEE has long been recognized as an outst, anding cool engine start simulator. But factors that are against it are its ability to be extremely flammable , and also instability while being stored. The latent heat of vaporization of DEE is much higher than that of diesel, but it has a similar heating value to that of diesel. It remains in the fluid state at room temperature, which decreases taking care of, and storage capacity issues. It also has anesthetic effects, which cause human health issues. [3,4]. However, information about utilizing DEE as a huge segment of a mix for biodiesel is constrained. DEE was employed for the ignition improvement by fumigation in various injection times directly or separately in an alcoholic diesel engine. [5].

The ideal portion of ETOH is somewhere in the range between 40-60%, , and for the two strategies, the measure of 50% DEE , and 50% ETOH with pre-injection timing. [8]. The ideal amount of DEE, in light of the thermal efficiency, alongside the advancement in injection timing, was seen as 10%. Tests revealed that the mixture greatly reduced smoke , and CO at all loads. There has been found an increase , and improvement in the maximum heat release, maximum pressure, , and maximum pressure increase. [6]. The addition of 5% DEE to the Diesel combination is the most efficient combination owing to the features of performance , and emission. The process of ignition is delayed by diesel fuel. Therefore the addition of DEE to pure diesel will actually lower the Cetane number [7,9]. Antioxidants are available to prevent oxidation [10]. DEE can be produced economically [11].

Methanol was added to Jatropha oil in the proportion 3:7 by volume. This combination is almost close to the methanol component needed for the formation of an ester with Jatropha oil [12]. The thermal break efficiency of double-fuel activities was better , and in contrast to the mixture of the methyl ester of Jatropa oil. In comparison to diesel oil, nitric oxide (NO) was below Jatropa Oil. Ignition delay was greater with neat Jatropa oil Peak pressure, , and the pressure increase rate was greater with all the techniques in contrast to neat Jatropa oil consumption. Smoke discharge estimates are 4.4 neat Bosch Smoke Units (BSUs). Jatropa oil, blended 4:1 BSU, mixed 4BSU, , and double fuel operated 4. BSU. [13].

Ceria is an ionic oxide with a high surface , and nano-size particles that has the fluorite structure (a generic open structure with simple oxygen transport). In a diesel , and biodiesel fusion with ethanol, the impact of cerium oxide added nano component has shown that the fusion of high-speed mixture , and ultrasonic bath stabilization increase stability. [14]. Cerium oxide nanoparticles may be used to allow complete fuel burning , and exhaust to be reduced as an added material in diesel , and blend consisting of biodiesel , and ethanol in diesel. The Introduction of cerium oxide is done in order to decrease carbon content available in the cylinder of the engine at wall temperatures [15].

Adding cerium to diesel leads to a significant drop in weighted size, , and the rate of oxidation has largely been increased. An investigation of the fundamental , and morphological features of a Ce-Zr blended oxide supported Mn oxide was carried out in this research, as well as the function of manganese oxide as a reactant in the oxidation of particulate matter resulting from diesel engine emissions is discussed [16]. The Mn-Ce-Zr impetus exhibits significant movement in the ash oxidation, resulting in the production of CO_2 , and CO as a side-effect in the temperature range 425-725 K. The ethanol reactions on respectable metal/cerium oxide surfaces are unpredictable [17].

Fuel additives based on aluminum oxide nanoparticles for diesel as well as diesel-biodiesel-ethanol mixtures. Aluminum oxide is used to stimulate oxygen , and oxidize carbon monoxide or oxygen in order to reduce NOx. Aluminum oxide nanoparticles were shown to be effective as an additive in diesel , and diesel-biodiesel-ethanol blends [18-19]. Given the fact that there have been relatively few studies on nanoparticles as biodiesel additives, experimentation of Al_2O_3 nanoparticles as biodiesel additives in Jatropha biodiesel blends to study the engine emissions , and performance has been limited. Also, no research evidence is available with tri-fuel blend amalgamated with nanoparticles. As a result, the current study is primarily concerned with comparing the performance , and emission characteristics of a single-cylinder direct injection diesel engine fueled by Al_2O_3 nanoparticles distributed in a tri-fuel mix. Also, the effect of the type of surfactant on the smoke is investigated in this research.

II. Experimental setup , and procedure

A. Preparation of Test Fuels:

The tri-fuel blend DEE-Diesel-Biodiesel was prepared by mixing the components at room temperature. On volumetric basis biodiesel 5%,10%,15%,20%,25%,30%,35%,40%,45%,50% & DEE 5% is mixed in 1000ml of diesel in a measuring flask , and stirred with mechanical stirrer at 3000r.p.m., and the tri-fuel blend is designated as 5DEEB5 etc. respectively. Manual mixing is used to combine pure JME biodiesel (B100) with pure diesel. B5, B10, B15, B20, B25, B30, B40, , and B50 are the designations for pure JME in the following proportions: 5, 10, 15, 20, 25, 30, 40, , and 50% vol percent with clean diesel.

To these fuel blends, diethyl ether of fixed concentration of 5% by vol is added to the above biodiesel blends , and designated as DEE5BD5, DEE5BD10, , and DEE5BD15, etc. To these fuel blends, nanoparticles of sizes 30 , and 60nm with 50 ppm &100 ppm concentrations were chosen. To stabilize the suspension of nanoparticles in the tri-fuel blend, two surfactants, namely Triton-X100& Brij58 of 1000 ppm &250ppm, respectively, were chosen , and then vigorously mixed with a JME biodiesel blend of 100 ml using a mechanical stirrer. The mixture was then supplemented with Al_2O_3 nanoparticles.

Improved chemical stabilization of the fuel blend with the surfactant was achieved by running a mechanical stirrer at 3000 rpm for 30 minutes, , and particle agglomeration was avoided by sonicating the fuel blend with an ultrasound liquid processor, which disrupts the nanoparticles , and therefore ensures better suspension. It can be observed from Fig. 1 that the Kinematic viscosity of the binary diesel/ JME blends increases with the addition of nanoparticles. Increasing resistance across layers of fluid is by the insertion of nanoparticles into the fuel , and thus increasing viscosity. The low fuel viscosity of the fuel injection pumps or the injection plunger, resulting in higher wear, does not provide enough lubrication. Increased viscosity can impact the atomization of exhaust gases.

The surfactant Triton-X100 , and Brij58 were considered separately , and added to these binary diesel/ JME blends in order to obtain a uniform , and stable suspension of the nanoparticle. Fig.1 shows the comparison of the viscosity of the diesel/ JME blend with the Al_2O_3 nanoparticle added at a st, andard temperature of 40 $^0{}_C$. Increases in the biodiesel concentration of JME in TFB blends are associated with an increase in viscosity, according to the research. However, the addition of nanoparticles to the tri-fuel blend regarding their size , and concentration has a marginal effect on the viscosity. But stabilized TFB with Al_2O_3 nanoparticles can be achieved by proper sonication using the ultra sound liquid process of 20kHz frequency maintained at constant room temperature for 2secs pulse on , and off mode. A stable suspension of this TFB with

Al_2O_3 nanoparticles with surfactants Triton-X100 , and Brij58 can be seen in Fig. 2.

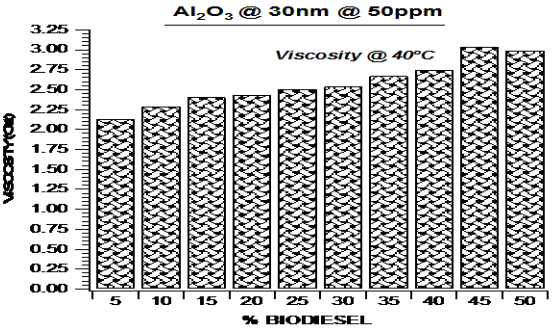

Fig .1 Kinematic viscosity of tri-fuel blend with nanoparticles

The performance, combustion, , and emission properties of a fuel mix on a single-cylinder, four-stroke diesel engine are determined in this research. The fuel samples were evaluated using a water-cooled engine with a power rating of 3.5 kW , and a rated revolution per minute of 1500. With high pressures, the engine may run on numerous injections , and cycles. The engine has an electronic injection control system kit that regulates the advance or retardation of injections. It controls both the timing , and amount of fuel.

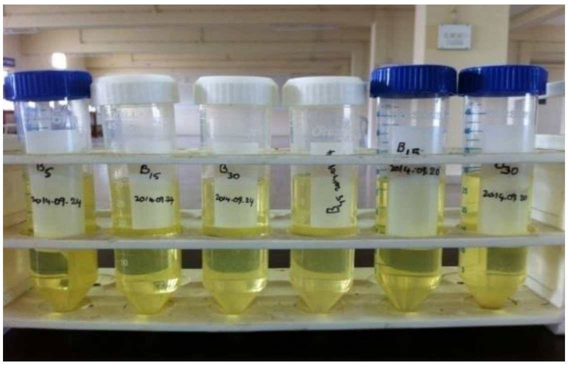

Fig.2 Stability of tri-fuel blend with nanoparticles

B. Experimental setup , and operating procedure:

To maintain constant pressure, the fuel supply system was attached with low-, and high-pressure circuits. A high-pressure pump powered by an electric motor serves as the fuel supply system for high-pressure injections. A common rail pressure valve is installed on the system that is controlled by a PIC microcontroller, which is used to keep track of and manage the fuel pressure. To help counteract variations in pressure, Kistler made pressure sensors that are hydraulically mounted. The engine data logger captures combustion data from the pressure transducer as well as signals from the crank angle encoder. The engine also has the provision for a mechanical injection system. For this experiment, the fuel used for testing in a single-cylinder diesel engine is a tri-fuel blend that consists Diesel-Biodiesel-Diethyl ether with nano metallic Aluminium oxide. The particle size was st, standardized to 25nm using a Ball milling machine, and Triton-X100 and Brij58 surfactant concentration chosen is 1000ppm, and 250 ppm respectively were chosen to suspend these nanoparticles in TFB.

The ultrasonic liquid processor of 1000kW capacity with 20kHZ sonication frequency. Sonication was done for the pulse of 2 secs on and off mode for 250ml fuel sample, and sonication is continued up to 30minutes. The dose of nanoparticles in TFB is changed between 25ppm and 50ppm. The engine utilized in this project is a computerized single cylinder variable compression engine equipped with an eddy current dynamometer that allows for load variation. The fuel injector is a mechanical injector that injects the fuel slightly higher fuel injection pressure of 230bar against the rated injection pressure of 210 bar. Indus diesel smoke meter and 5 gas analyzer are used to record the engine emissions. Experiments are conducted with neat diesel, neat biodiesel with DEE, and tri-fuel blend 70Diesel-25biodiesel-5DEE with nanoparticles Al_2O_3 of size 25nm, and concentration 25ppm, and 50ppm respectively at 200bar injection pressure.

TABLE I: Specifications of The Engine Test Rig

Sl. No.	**Parameter type**	**Specification(s)**
1	Engine	Kirloskar
2	Engine Model	AV1
3	Engine type	Single cylinder, 4 Stroke, Direct Injection, Water-cooled CI Engine
4	Engine Power Rating	3.7 kW@1500rpm
5	Engine speed	1500rpm
6	Engine fuel type	Diesel
7	Bore & Stroke values of Engine	80 X 110 mm
8	Displacement in m	553E-6m^3
9	Compression Ratio	16.5:1, Range: 13.51 to 20
10	Injection Pressure in bar	200 bar-350bar
11	Cylinder Pressure in psi	Piezo Sensor, Range: 200 psi
12	Nozzle size	1 hole, Ø0.0020 m
13	Dynamometer type	Eddy current dynamometer
14	Orifice Diameter in mm	20 mm

Extreme care has been taken to flush out the oil leftover in the fuel tank , and also in fuel filter. For this emptying the fuel tank by opening the drainage cock to flush out the previous fuel left over in the fuel tank after that running the engine with neat diesel for sufficient time. Any fuel left in the fuel filter is completely consumed before testing the fuel blend in the engine by closing the fuel supply from the tank.

For every sample, any airlock in the fuel line is removed, and the engine Is run with the tri-fuel blend for a long duration, almost for 2-3 hours, and then data is recorded on the engine for different operating conditions. The engine is run for a period of 30-40min until much change is not observed in the water line temperature after those readings are recorded. The fuel usage was tested for 10cc three times, and the average was used for computations. To perform the tests, the Eddy current dynamometer was utilized.

A gas analysis instrument named the Indus 5 was used, which is an Indian make to analyze the exhaust contaminants from the engine. In compliance with the requirements of the Automotive Research Authority of India (ARAI), Indus Instruments' Diesel Tune 114 smoke meter was used to measure the smoke intensity. It is used to measure the strength of the smoke in the Hatridge Smoke Unit (HSU). To first collect reference data, the engine was operated on diesel fuel. For each fuel sample, two sets of measurements were taken, and the average of the two sets was utilized for the analysis. The validity of experimental results is contingent on the statistical significance of the findings.

A variety of different variables contribute to the experimenter's uncertainty, including observations, environmental variables, and instruments. The engine should be run at least 30minutes before conducting the experiment with any load; by this, the cooling temperature of the water doesn't vary significantly. Engine data are obtained at a minimum of 3 times for each load, and graphs are drawn using the average values. The parameters' measurement ranges and accuracies were shown in Table 2. Experimental parameters at injector pressure 210bar have a variance between 0.58% and 1.97% depending on the uncertainty analysis for engine efficiency, emission, and smoke parameters.

TABLE II: Depiction of The Measuring Range and Accuracy of The Measurable Parameters.

Measured qty.	**Measuring**	**Accuracy**
Speed range	0-2000	+/- 1 rpm
Specific fuel consumption	0-3 kg/h	0.001
Exhaust gas temperature range	30-1000 ^{0}C	+/- 1 ^{0}C
Load range	0 kW-2.8	+/- 0.01
Torque range	0-30 Nm	0.01 Nm
In -cylinder Gas Temperature	20-2000 ^{o}C	0.01 ^{o}C
Ignition Delay range	0-20 deg	0.1 deg
Air-fuel ratio range	0-100	0.01
Peak Pressure range	1-200 bar	0.01 bar
Average combustion Duration	0-100 deg	0.1deg
Averaged maximum rate of	0-10	0.01
Averaged maximum rate of	0-100	0.01
Crank Angle range	0-360 deg	0.1 deg

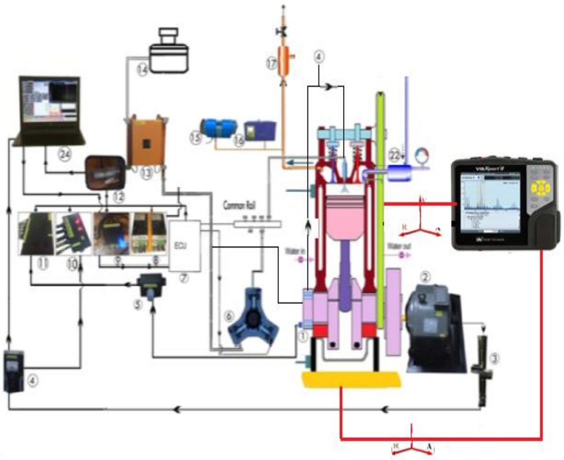

Fig.3. Schematic diagram of the computerized multifuel high-pressure engine test rig.

Computer with data logging software 2. Ethernet 3. Fuel measuring sensor unit 4. Smoke meter 5 gas exhaust analyzer 6. Fuel tank 7. Exhaust silencer 8. Diesel injector 9. Air inlet tank 10. Pruftecnik vibration Measuring Instrument 11. Load cell 12. Fuel governor 13. High-pressure fuel injection pump 14. The electronic control unit 15. Throttle controller 16. Load indicator 17. Pressure dag 18. Crank angle encoder 19. Speed dag 20. AC to DC converter 21. Air-cooled eddy current dynamometer

Fig.4. The computerized multifuel high-pressure engine test rig

III. Results, and Discussion:

A. Performance characteristics:

Fig5 & 6 show the fluctuation in brake-specific fuel consumption for various nanoparticle concentrations for both Triton-X100 and Brij58 surfactant. With increasing load, the specific fuel consumption of tri-fuel blends containing Al_2O_3 nanoparticles reduces. Figures 5&6 shows that Al_2O_3 shows better SFC for both 25ppm&50ppm concentrations with Triton and Brig 58 surfactant. This is owing to Al_2O_3's superior thermal conductivity, fast combustion, and enhanced premixed combustion.

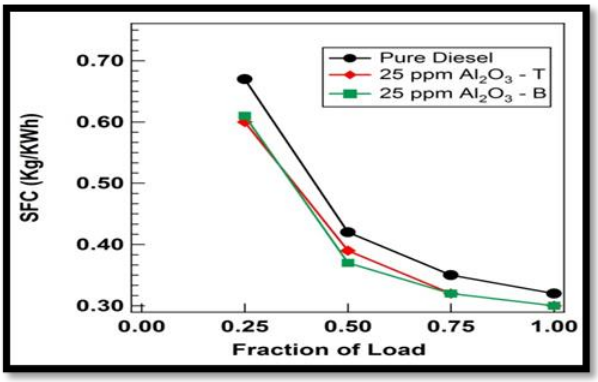

Fig.5 SFC vs. Fraction of load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3-B

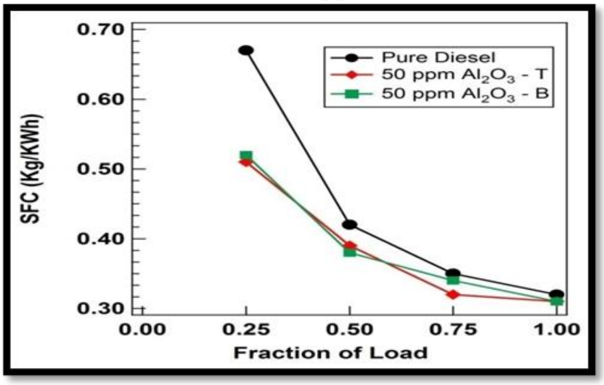

Fig. 6 SFC vs. Fraction of load for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B

The lowest specific fuel consumption of 0.31kg/kWhr is recorded at Full load for B25DEE-Brig58for Al_2O_3 nanoparticles at the same time diesel has 0.34kg/kWhr. This decrement of SFC is mainly because of the modification of the fuel blend JME25 with the addition of 5% DEE and nanoparticles. This shows that the addition of small amounts of nanoparticles improves SFC [20,21]. This improvement in SFC is mainly due to the higher combustion efficiency. More oxygen, and increased combustion efficiency due to aluminum nanoparticles, resulting in less fuel consumption and lower BSFC. The use of nano aluminum oxide enhances the oxidation rate of the fuel, increasing the overall output of the system. S. Imtenan et al. also found that adding minute amounts of DEE to n-butanol fuel blends enhanced their viscosity, resulting in a decrease in SFC when compared to plain diesel fuel. [22]. The thermal efficiency of the brakes is a function of the quantity of fuel energy converted to mechanical output in proportion to the engine characteristics of the vehicle. Figure 7&8 shows the there is an increase in the thermal brake efficiency with an increase in load. B25DEE blend with Al_2O_3 –B25ppm is exhibiting the highest brake thermal efficiency of 29.03%, whereas neat diesel is exhibiting 27.78% [23,24]. Because nano Al_2O_3 addition decreases the time required for evaporation of the test fuel and therefore shortens the physical delay, this so ensures that the fuels are fully used in the combustion chamber. Al_2O_3 –B nanoparticles help incomplete combustion in comparison to the base diesel fuel. Better burning, atomization, and fast evaporation of the nanoparticles distributed in fuel lead to an increased surface area of fuel exposed to oxygen molecules, resulting in improved air-fuel mixing. No increase in thermal brake performance for Al_2O_3 nanoparticles is observed as the dosage amount is increased. This may occur due to heavier loading of nanoparticles may not actively dissipate the heat in the fuel blend, and also, there may be a decrease in the chemical activity of the fuel catalyst [25,26]. Adding 5% DEE to J20 biodiesel improved thermal brake efficiency by 2.8%, while adding 10% DEE boosted thermal brake efficiency by 5.3%. [27].

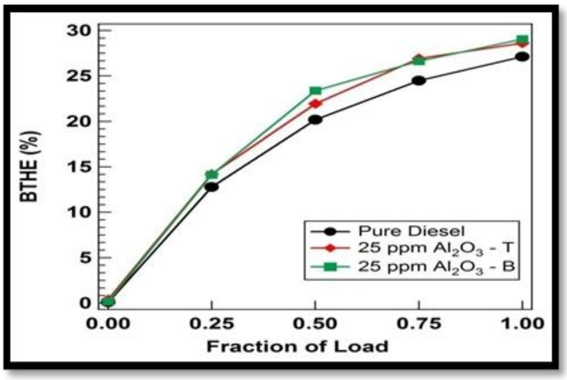

Fig.7 BTHE vs. Fraction of load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3-B

However, in this present work, the amount of DEE is limited to 5% in binary Jatropa-diesel blend of J25 due to the flashpoint temperature. Hence the present findings confirm that the addition of Al_2O_3 –B25ppm with 5% DEE also increased the thermal brake efficiency by 1.25%, which is consistent with earlier published results as discussed. Fig9 & 10 illustrate the change in the air-fuel ratio for various nanoparticle concentrations while the engine is operated at various load situations.

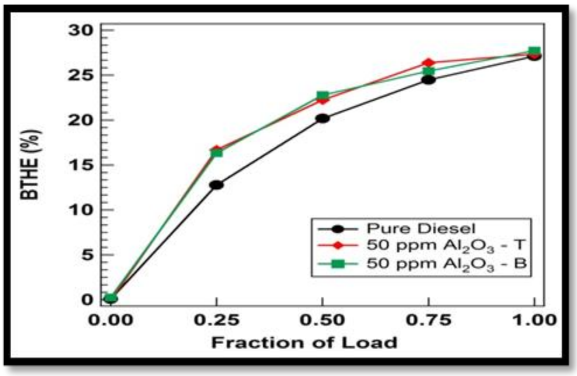

Fig.8 BTHE vs. Fraction of load for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B

Figures 9 and 10 demonstrate that while the engine speed was fixed at 1500 rpm and the engine load was changed, the air to fuel equivalency ratio rose. The equivalence ratio is increasing for Al_2O_3 ppm nanoparticles for higher concentration indicating the heavier dosage of nanoparticles promotes lean combustion is possible [28]. Because Al_2O_3-np has a high surface area, it participates in burning in an oxygen-rich environment. It can be observed from figs9&10 that at ¾ & full load operating conditions both diesel, and TFB-np have an equivalence ratio similar to each other, indicating that TFB-np was promoting lean combustion at ¾ & Full load engine operating conditions.

This lean combustion is achieved for TFB-np at a lower concentration of 25ppm Al_2O_3-np particles. As the concentration of Al_2O_3-np participants is further increased to 50ppm, one can see from fig9&10 that the equivalence ratio is decreasing, indicating that there is an agglomeration of Al_2O_3-np particles, and these particles are not actively participated during the combustion process leading to a rich mixture burning. The same trend is also reflected in the HC emissions, as can be seen in HC emission in figs 25&26.

At 3/4 Full load conditions, the highest peak pressures are recorded for Al_2O_3 nanoparticles with Triton, and Brij surfactants, as shown in Figure11&12 indicating that surfactant type also affects the ignition delay. With increasing in concentration of Al_2O_3, the ignition delay and peak pressures are also changing for Triton &Brij surfactants. Figure 13, &14 indicates that the peak pressure with the tri-fuel blend B25DEE with nano fuel additives is greater because of the improvement in the formulation of the air-fuel mixture as a result of the reduction in fuel viscosity.

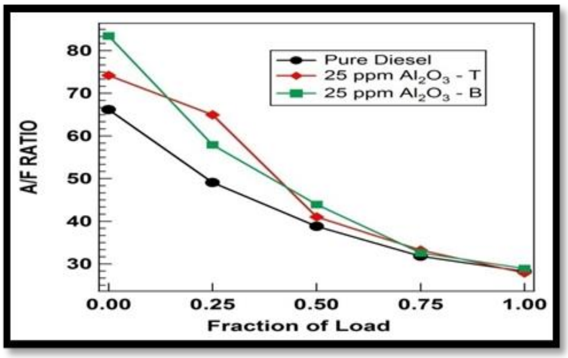

Fig. 9 A/F ratio vs. Fraction of load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3-B

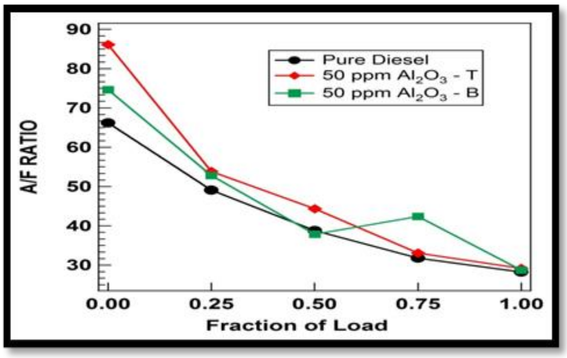

Fig.10 A/F ratio vs. Fraction of load for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B

This shows that increase in engine load, the peak pressures are also Increase, and for the engine operating at full load conditions, the peak pressure measured for 50ppm Al_2O_3-B the peak pressure is 71.54 at 365CAD. But for 25ppm, Al_2O_3-B gives higher peak pressure of 72.26 at 361CAD, indicating that 25ppm Al_2O_3-B has better-premixed combustion, and maximum amount of fuel is ignited during this period, and diffused combustion has reduced [29]. AOP varies between 5-and 9-degrees ATC while using st, standard diesel fuel. [30]. For all fuels and loads, the maximum pressure occurs between 1 and 6 crank angle degrees after the top dead center (table3). At maximum load, the ignition delay for tri-fuel mixes, including nanoparticles, is longer than for pure diesel operation. This implies that in pre-mixed combustion, a greater quantity of fuel is used.

TABLE III SOC, EOC, Ignition Delay, and Ignition Duration for Pure Diesel, 25ppm Al_2o_3-T, and 25ppm Al_2o_3 -B

S.no	Product	SOC (deg)	EOC (deg)	Ignition delay	Ignition duration
1	Pure diesel	-14	28	-9	42
2	Al_2O_3 25ppm+B	-11	41	-12	52
3	Al_2O_3 50ppm+B	-13	41	-10	54

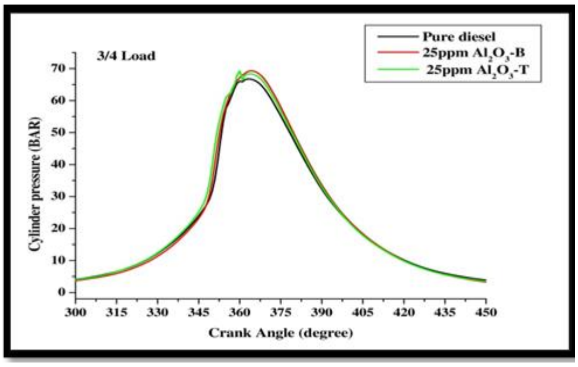

Fig. 11 Cylinder Pressure vs. Crank Angle for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3 -B at ¾ th Load.

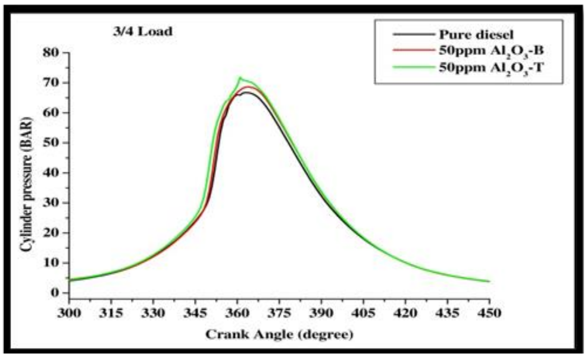

Fig. 12 Cylinder Pressure vs. Crank Angle for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B at ¾ th Load.

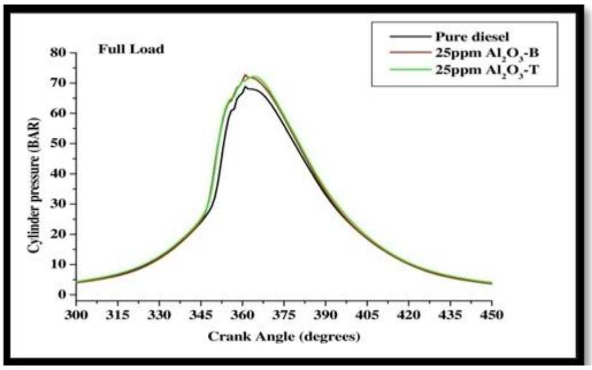

Fig.13 Cylinder Pressure Crank Angle for pure diesel, 25ppm Al_2O_3-T , and 25ppm Al_2O_3 -B at Full Load.

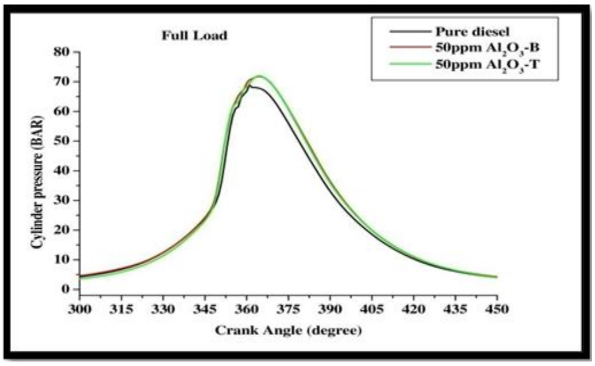

Fig. 14 Cylinder Pressure vs. Crank Angle for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B at Full Load.

Combustion characteristics:

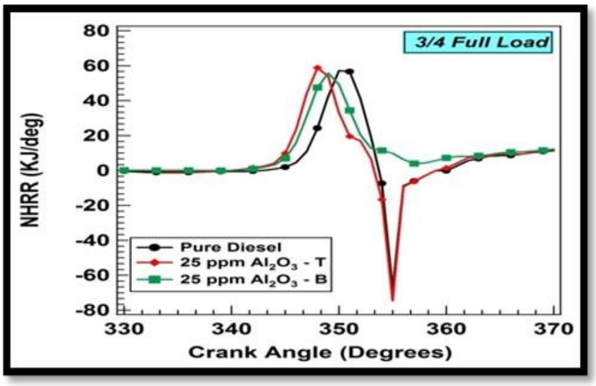

Fig. 15 NHRR Vs. Crank Angle for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3 -B at ¾ th Full Load.

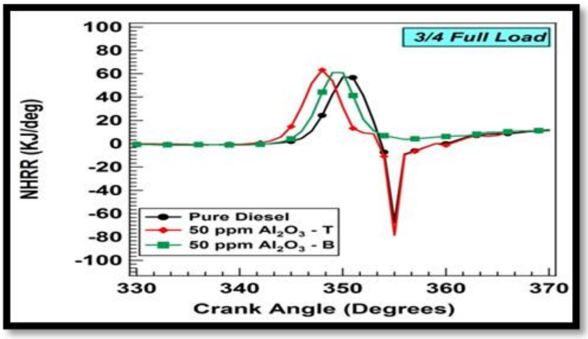

Fig. 16 NHRR vs. Crank Angle for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B at ¾ th Full Load.

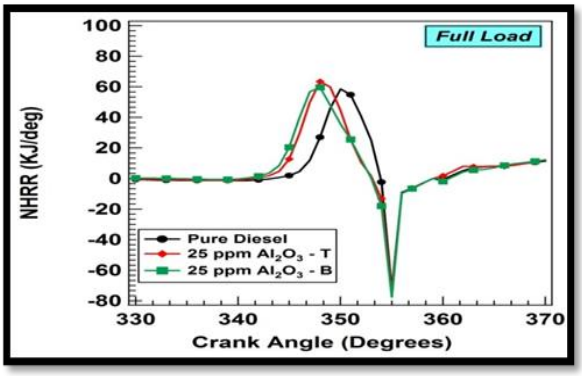

Fig. 17 NHRR Vs. Crank Angle for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3 -B at Full Load.

Neat 100% diesel, the maximum heat release rate is only 58.53kJ at 349CAD.Figure15&16 show that at 3/4th loads, higher concentration Al_2O_3 nanoparticles release maximum heat for both Triton-X100 and Brij58 for 50ppm nanoparticle concentration [31,32]. Figure17&18 show that for Full load conditions, a lower concentration of Al_2O_3 nanoparticles, 25ppm concentration, gave better heat release than 50ppm. Figure 19&20 shows that the quantity of heat emitted by Al_2O_3 nanoparticles is more than that of plain diesel when both Triton, and indicating a higher thermal efficiency of the brakes

And a lower specific fuel consumption as compared to other blends [33].

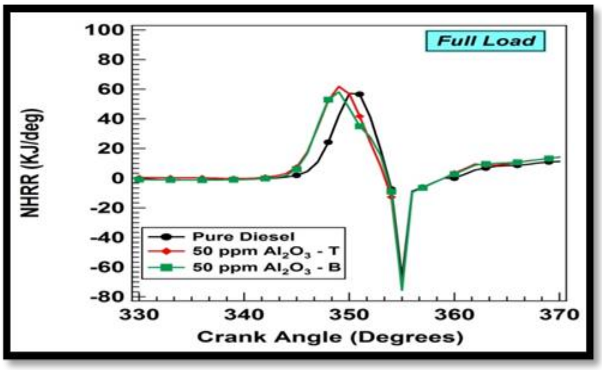

Fig.18 NHRR vs. Crank Angle for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B at Full Load.

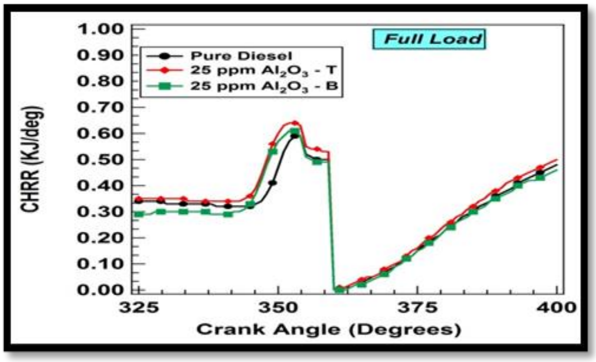

Fig. 19 CHRR Vs. Crank Angle for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3 -B at Full Load.

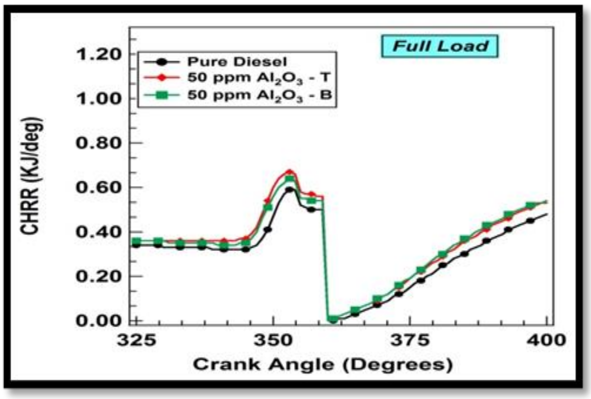

Fig.20 CHRR vs. Crank Angle for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B at Full Load.

Al_2O_3 showed not much difference in heat released in diffused combustion zone with an increase in particle concentration from 25ppm-50ppm. Additionally, the occurrence of the maximum cumulative heat release rate is consistent across all tri-fuel mixes with the varying nanoparticle and surfactant concentrations. It was observed that the surfactant Triton-X100 has higher heat release rate as compared to the Brij58 indicating that surfactant is critical for regulating the rate of combustion and heat release.

B. Emission Characteristics

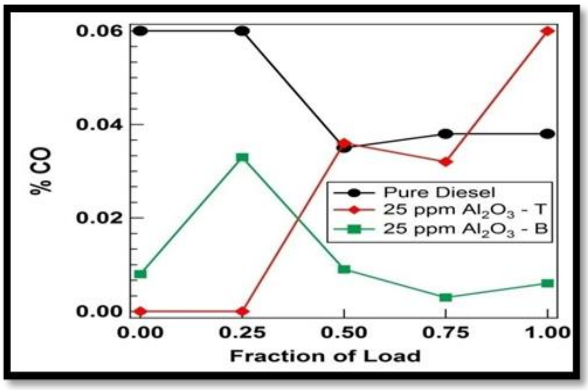

Fig. 21 %CO Vs. Fraction of Load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3 -B

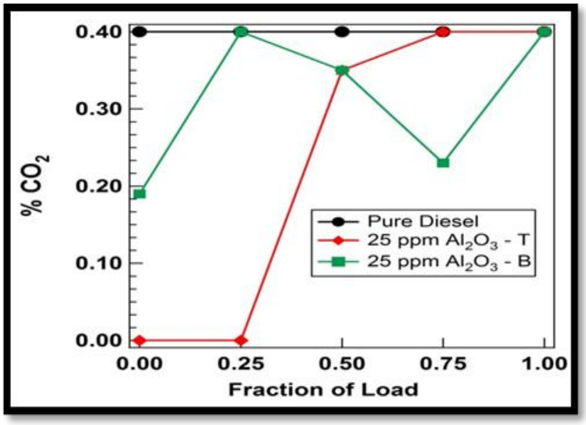

Fig.22 %CO_2 Vs. Fraction of Load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3-B

Figure21&22 shows that when CO% percentage decreases with increasing load simultaneously, CO_2 % increases. This is due to the oxidation of CO into CO_2 in the presence of oxygenated fuel Diethyl ether and biodiesel in the tri-fuel blends. Applying nanoparticles based on metal oxide ensured that CO emissions are reduced. Possibly attributable to the increased oxygen content, which results in a strong catalyst activity (by higher surface area/volume of a nanoparticle ratio) with metal-dependent oxide nanoparticles in the mixtures. Increased ignition properties of nanoparticles. It can be concluded from the Figures21&22 that the CO, and CO_2 mainly depend on the type of nanoparticles since these emissions trend is same for both Triton &Brij surfactant [34,35]. A trade-off result is obtained for CO & CO_2 between Triton-X100 & Brij58 surfactant as seen in figs21&22. Triton-X100 emits 0.06 percent more CO than Triton-X100 does at full load. Similarly, the CO percent released rises continuously as the engine load increases for Triton-X100, however contrary to Brij58, the CO percent released falls as the engine load increases. This trade-off behavior is noticed for Brij58 for CO_2 also. This demonstrates that the quantity of CO and CO_2 emitted is mostly determined by the kind of surfactant employed to stabilize the fuel in the presence of nanoparticles. The TFB with Al_2O_3-np with both Triton-X100 & Brij58 surfactant has less release of CO & CO_2 when compared to the pure diesel. CO emissions were decreased because of the improvement in combustion resulting from the Alumina nano-additive diesel fuels. (Refer Figures 21&22). At low loads, there was no discernible difference in CO emissions between the tested fuels due to the reduced amount of fuel provided, which resulted in a lower temperature. The fuel supplied increased with higher loads, which dispersed the nanoparticles in the fuel to completely combust. Sadhik Basha et al. have found similar results using cerium oxide nanoparticles in binary diesel blends [36]. For the Jatropa biodiesel blend, Sharma et al. found that blending carbon nano tube-laced jatropha biodiesel caused a decrease in CO emissions with a corresponding reduction in ignition delay, resulting in a 50-ppm dose of carbon nanotubes that reduced CO emissions by 10 percent. [37]. Figures 23&24 demonstrate that when load rises, NOx levels increase owing to an increase in combustion temperatures. NOx emissions reduce with an increase in nanoparticle concentration for both Triton –X100 and Brij58 surfactants [38]. This is due to the retarding of the SOC one sees that SOC for Al_2O_3 –B25 is -12CAD, but for neat diesel, it is -9CAD. Complete combustion is aided by metal oxide nanoparticles which enhance the rate of oxidation and use less oxygen in the chamber. The results show that Triton-X100 reduces better NOx emissions when compared to the Brij58 surfactant. The highest NOx reduction up to 200ppm is obtained for both Al_2O_3 –T50ppm, and Al_2O_3 –B25 ppm [39], satisfying Euro3 norms. Nanoparticle doped additive binary diesel / JME fuel is more efficient in the reduction of NOx. But when a surfactant is used for stabilized suspension of nanoparticles, NO_x reduction mainly depends on the nature of the surfactant. One can see in the fig23&24 Triton-X100 successfully reduces

NOx emissions to levels lower than those produced by neat diesel at all engine loads, while Brij58 and neat diesel fuel both emit the same amount of NOx when the Al_2O_3 - nanoparticle concentration is restricted to 50ppm.

This result will indicate that for effective control of NO_x using nanoparticle additives, particle concentration plays a significant role. One can see from fig23&24 that a lower concentration of 25ppm Al_2O_3-np is highly effective for both Triton-X100 & Brij58 surfactant in NO_x emission reduction. Simultaneously, when the concentration of nanoparticles in TFB blends rises, NOx emissions increase linearly. Similar research findings are published earlier with multiwalled carbon nanotubes MWCT by Selvan et al. [40]. Sadhik Basha et al., on the other h and, discovered that when Alumina nanoparticles were included in diesel fuels, the magnitude of NOx emissions was marginally reduced when compared to clean diesel [41].

This limitation is mainly they have not used any ignition improver for effectively controlling the combustion, due to which the reduction in NO_x is very marginal. This can be seen in the present research work the addition of DEE along with Al_2O_3-np in the binary Diesel/ JME blend was much effective in reducing the NO_x in comparison to the pure diesel, as shown in fig23&24. Fig 25 & 26 depicts the variation in HC emissions as a function of engine load, and biodiesel has lower HC emissions since the test fuel's combustion is improved as well as the additive mix because it includes oxygen. The emission of HC is an unfinished combustion element. Figure 25 shows as the load increases, the HC emissions rise as a consequence of the low cylinder pressure and temperature, which result in a considerably slower combustion rate.

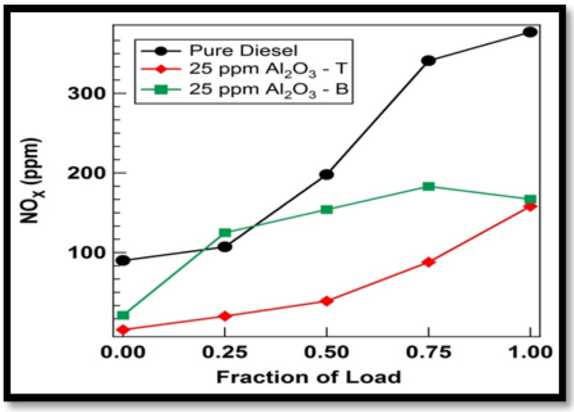

Fig. 23: NOx Vs. Fraction of Load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3 –B

Using Al_2O_3 nanoparticles in the tri-fuel mix with Triton-X100 and Brij58surfactants reduces HC emissions. Using 25ppm Al_2O_3 nanoparticles with both surfactants decreased HC emissions less than plain diesel. A higher oxygen concentration allows for the full burning of the fuel.[42]. According to Idris et al., emissions from Alumina nano-additive diesel fuels were somewhat decreased when compared to plain diesel. The combustion properties were enhanced using nanoparticle additives in diesel fuel. At higher loads, Alumina nanoparticles serve as an oxidation catalyst, speeding up hydrocarbon oxidation

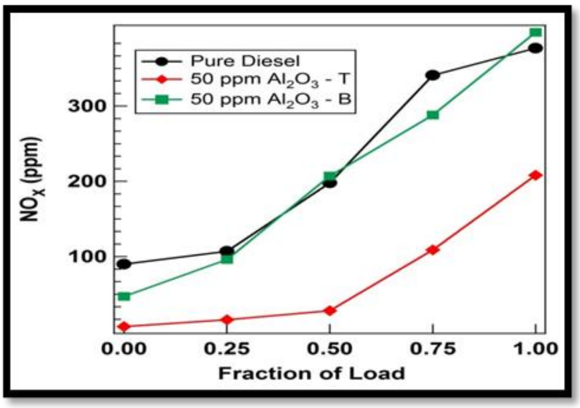

Fig. 24: NOx Vs. Fraction of Load for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3-B

As a result, a small reduction in HC emissions occurs due to hydrocarbon oxidation, which is greater than the reductions produced by the Alumina nanoparticle effect.

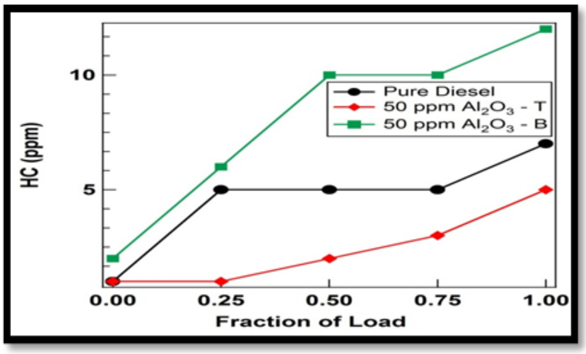

Fig. 25: HC Vs. Fraction of Load for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3 -B

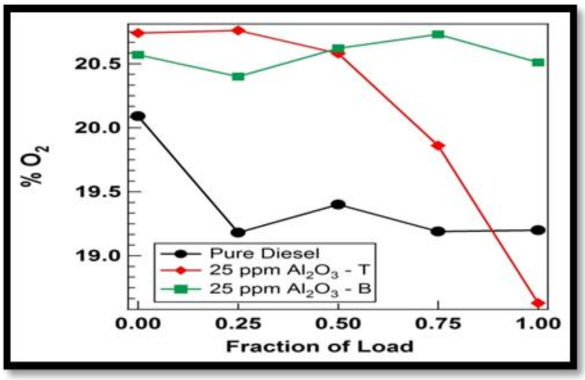

Fig.26: %O_2 Vs. Fraction of Load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3-B

Additionally, they found that there was no significant change in the amount of HC emission at lower and intermediate loads [43]. However, in the current study, substantial reductions in HC emissions were obtained under both part-, and full-load conditions, as seen in fig25&26. This substantial decrease in HC emissions is achieved because of the controlled dosing of Al_2O_3 – np and the use of a non-ionic surfactant such as Brij58 or Triton-X100.

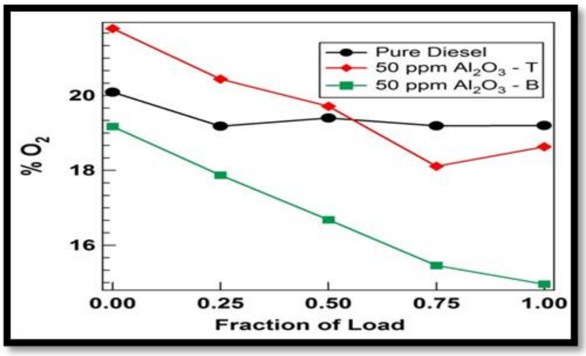

Fig 27: %O_2 Vs. Fraction of Load for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3 -B

Figure 26&27 illustrates the fluctuation in O_2 with increasing load, showing that O_2 declines as load increases. The results obtained are in coherence with CO results, as shown in Figure 21. With the increase in nanoparticle concentration, O_2% also increases since the nanoparticles are metallic oxide which generates more oxygen during oxidation.

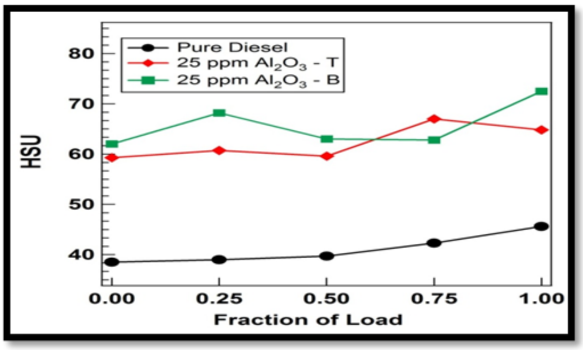

Fig.28: HSU Vs. Fraction of Load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3-B

Increased oxygen content in blends promotes combustion, resulting in an increase in BTE, as seen in Figure5&6. Smoke in a diesel engine's exhaust indicates poor fuel combustion. Blends with a higher oxygen concentration have a lower smoke opacity [44] that can be seen in Figure28. The engine running on a tri-fuel blend containing Al_2O_3 nanoparticles, Triton-X100, and Brij58 surfactant passed the smoke test under all engine loading conditions, indicating that the presence of biodiesel Jatropa methyl ester and Diethyl ether may be responsible for the reduction in smoke intensity. The presence of more concentration of nanoparticles increased the smoke intensity slightly. Brij58 surfactant releases more smoke when compared to Triton-X100 surfactant for the same fuel combination where the smoke intensity increases from 57.7HSU to 69.1HSU, indicating that Brij58 surfactant gives more smoke at part loads, but for full load engine operation, the smoke intensity is almost the same as that of Triton-X100 surfactant. The results obtained are in line with Figures 30-32, where K/M variation is the same as that of HSU. Results show that Al_2O_3 nanoparticles confirm that the smoke intensity depends mostly on the surfactant used [45].

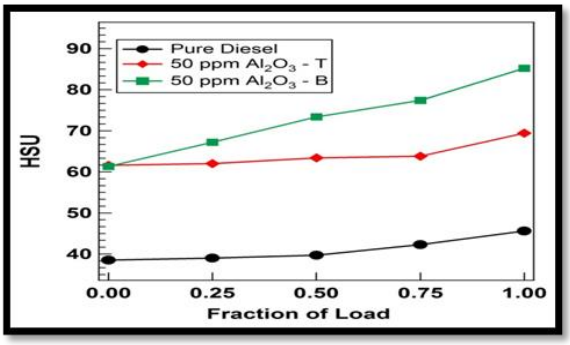

Fig 29: HSU Vs. Fraction of Load for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3 -B

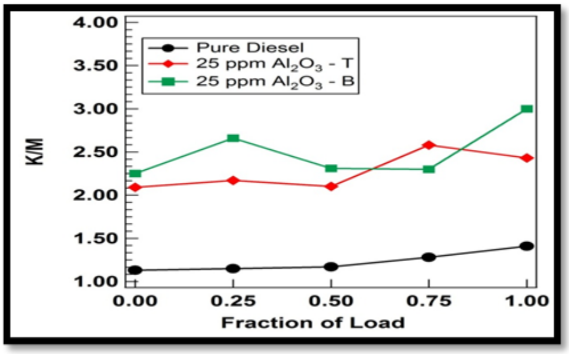

Fig.30: K/M Vs. Fraction of Load for pure diesel, 25ppm Al_2O_3-T, and 25ppm Al_2O_3-B

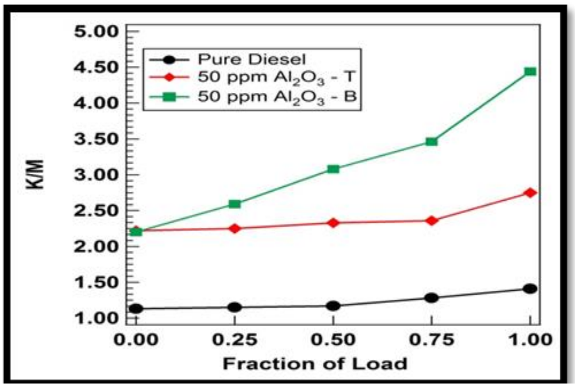

Fig 31: K/M Vs. Fraction of Load for pure diesel, 50ppm Al_2O_3-T, and 50ppm Al_2O_3 -B

Jatropha biodiesel works well in diesel engines. Several studies found ethanol to have lower BP, BTE, and BSFC than diesel. These were the results of the exam. More HC and PM than diesel. But NOx emissions increased. It reduced cylinder pressure and heat release (JB20, JB40, JB80, and JB100). 100% Jatropha biodiesel was outperformed by JB20. It seems that Jatropha biodiesel may soon be a viable alternative fuel.[46]

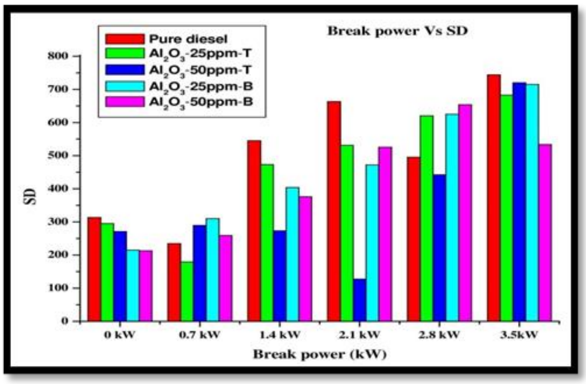

Fig.32: SD Vs. Break Power for pure diesel, 25ppm Al_2O_3-T,25ppm Al_2O_3-B, 50ppm Al_2O_3-T, and 50ppm Al_2O_3 -B

IV. CONCLUSIONS

Here is a summary of the performance, emissions, and combustion characteristics of a CI engine that is powered by a tri-fuel mixture that contains Al_2O_3 nanoparticles:

1. The viscosity rises somewhat when the surfactant concentration is increased from 50ppm to 100ppm, and a small increase in viscosity is seen as the nanoparticle size and concentration are increased.
2. The amount of DEE addition is limited to 5% only due to the limitations of the flash point at 40^0C as per ASTM st, standards. As the dosage amount rises, no improvement in thermal brake efficiency is seen for Al_2O_3 nanoparticles. The result obtained is in accord with SFC values.
3. Al_2O_3 –B25ppm with 5% DEE increased the thermal brake efficiency by 1.25%. At higher engine load, Al_2O_3 of 25ppm concentration is promoting lean combustion having a higher equivalence ratio of 38:1 as compared to 32:1 for 50 ppm concentration. At ¾, and Full load engine operating conditions, Al_2O_3-np particles of 25ppm for both Triton-X100 & Brij58 surfactant have almost similar equivalence ratio as that of neat diesel fuel.
4. Better premixed combustion is observed with Brij 58 surfactant for TFB delivering higher peak pressure of 72.26bar. Compared to Brij58 surfactant, the maximum in-cylinder combustion peak pressure is noticed for Triton-X100, giving 75.51bar, while for Brij58, it is limited for only 72.26bar. At 3/4th loads, higher concentration Al_2O_3 nanoparticles of 50ppm release maximum heat for both Triton-X100 and Brij58 for 50ppm delivering 92kJ/deg. A lower concentration of 25ppm Al_2O_3-np is more effective in mitigating NOx emissions for both Triton-X100 & Brij58 surfactants.
5. The addition of DEE to binary diesel/JME blends resulted in a simultaneous decrease in NOx and HC emissions. Smoke levels rose when Triton-X100 and Brij58 were added to neat diesel since diesel released only 48HSU compared to 62HSU for Triton-X100. The amount of smoke released mainly depends on the surfactant since Brij58 released 82HSU as compared to 62HSU for Triton-X100.

Hence the present research results confirm that Triton-X100 surfactant is not suitable for Al_2O_3 nanoparticles in the tri-fuel blend. Brij58 surfactant gave better results with Al_2O_3 nanoparticles in the tri-fuel blend. The tri-fuel blend B25DEE5 with Al_2O_3 nanoparticles of size 25nm., the optimum concentration is 25ppm, and the suitable surfactant is Brij58. The optimal surfactant concentration is 250ppm.No no advantage in engine performance, and emissions are observed with a higher concentration of Al_2O_3 nanoparticles greater than 25ppm for the tri-fuel blend. The addition of DEE in the fuel blend with Al_2O_3 -np with surfactants Triton-X100 & Brij58 improved the physicochemical characteristics of the fuel blend that contribute to the formation of a stable suspension of the fuel blend with Al2O3 -np. In the present research work, it is found that for effective reduction of NO_x emission, the nanoparticle concentration in the fuel blends should be at a low dosage to suit for Non-Ionic surfactants. Also, in the present research work, it is noticed that Ignition improver DEE is required for successful NOx and HC emission reductions in the presence of Al_2O_3 nanoparticles in fuel mixes. Finally, the study indicates that combining DEE with Al_2O_3 nanoparticles in fuel mixes results in a significant improvement in the combustion, performance, and emissions of the engine.

Acknowledgments

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