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Effect of Aluminum Oxide Nano-Particle in Jatropha Biodiesel on Performance, Emissions and Combustion Characteristics of D I Diesel Engine

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Abstract: In the present energy scenario of increased energy demand, rapid depletion of petroleum resources and increased environmental problems, the search for new renewable and alternative fuels have gained momentum. This study represents an experimental investigation to examine the effect of nano additives on single cylinder DI diesel engine performance at variable operating conditions. In this work alumina nanoparticles having average size of ~10 nm were dispersed in a mixture of jatropha methyl ester and conventional diesel fuel (20% jatropha biodiesel and 80% diesel fuel) at proportion of 20, 30 and 40 parts per million. The obtained results were compared with neat diesel and B20 as base fuels. It is found that, the appropriate nano-additives dose corresponding to optimal engine performance is about 40 ppm of alumina nanoparticle. At this dose, the overall BSFC is reduced by about 12.5%, engine thermal efficiency is increased up to 12%, and exhaust gas temperature is reduced by 13%. Along with percentage reduction of smoke opacity by 20 %, unburned hydrocarbon by 10 %, carbon monoxide by 29 % and nitrogen oxides by 13% compared with the corresponding values obtained when only a blended fuel of 20% biodiesel is used. Such type of biofuel based Nano fluids having improved performance characteristics can be utilized directly as an alternate fuel for diesel engines.

Keywords: Alumina nanoparticles, Jatropha biodiesel, engine performance, Exhaust emissions, Combustion characteristics.

I. INTRODUCTION

The wide applications of the diesel engines increase the consumptions of the fossil fuel. At the same time, the fast depletion of the conventional fossil fuel and the increase of its price, increased pollution due to the excess use of such petroleum and diesel fuel for varied energy requirements is another important issue to be addressed that make the looking for alternative sources of fuel is urgent objective. In this state, the biofuel is a promising alternative substitute of the conventional diesel fuel, as it is environmental friendly renewable fuel. Many researchers have contributed their work toward reduction of hazardous tail pipe emission from the engine using different methods such as engine modification, fuel alteration and exhaust gas treatment. Fuel alteration may include use of biodiesel produced from vegetable oils as an alternative fuel to diesel. In this context, biodiesel has emerged as one of the potential renewable energy to replace current commercial diesel due to their low emission characteristics and equivalent energy density. Biodegradable and nontoxic fuel can be easily produced through transestrification reaction [1, 2].In this context, several researchers recently reported that such drawbacks of biodiesel can be improved by dispersing different types of nanomaterials such as alumina, copper oxide, multi-walled carbon nanotubes (MWCNT’s) into the biodiesel as the base fluids. Since, dispersing such nanomaterials can enhance the thermo-physical properties of the biodiesel as compared to the base fluids due to the unique physical, thermal, and catalyst properties of the nanomaterials. Furthermore, such nanomaterials have high surface to volume ratio and hence larger surface contact area during the rapid oxidation process. In addition, due to size dependent properties they can have the potential to release higher energy and hence can improve the fuel characteristics of the diesel engines [2-6]. D. Srinivas Rao et. al. [7] conducted an experimental investigation on the combustion characteristics of alumina nanoparticles dispersed jatropha biodiesel based nanofluids by dispersing the alumina nanoparticles having average size of ~13 nm in jatropha biodiesel with 0.1 volume fraction. The test results revealed that the evaporation time of one year older stable ~13 nm alumina nanoparticles dispersed nanofluids significantly improved and were comparable to that of the commercially available diesel fuel and such type of biofuel based nanofluids having longer term stability and improved combustion characteristics can be utilized directly as an alternate fuel for the future diesel engines. The addition of 25 to 50 ppm of alumina nanoparticles (of size 51 nm) on jatropha biodiesel fuel leads

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to a significant improving of engine mechanical and emission performance [8].

Prabu Arockiasamy et al. [9] experimentally investigated in a single cylinder DI diesel engine the effect of nanoparticle as additive in Jatropha biodiesel at 30 parts per million and the engine performance, combustion and emission characteristics were compared with neat diesel as base fuel. The results revealed that percentage reduction of NO emission by 9 %, Smoke opacity by 17 %, unburned hydrocarbon by 33 % and carbon monoxide by 20 % along with 5 % improvement in brake thermal efficiency. Basha and Anand [10] blended Carbon Nanotube at 25, 50 and 100 ppm in Jatropha methyl ester emulsion (5% of water and 2% of surfactants (by volume)) and found drastic percentage reduction of NO by 29 % and smoke opacity by 28 % in a single cylinder, four-stroke, direct injection diesel engine. An experimental investigation was carried out with alumina nanoparticle, blended at 25 and 50 ppm in water diesel emulsion and observed drastic percentage reduction of NO by 27 %, smoke opacity by 40 % with marginal reduction of HC and CO emission [11]. Amit and Sudhir Kumar [12] carried out an experimental analysis to evaluate the impact on the performance of direct compression ignition engine by adding cobalt oxide and iron oxide nano particle in jatropha biodiesel in mixed proportion of 10, 20, 30, 40, 50 and 60 parts per million. The range of nano particle size was 30-70 nanometer. The notable advancement in brake thermal efficiency, brake specific fuel consumption and exhaust gas temperature is observed.

Biodiesel blend B10 with 0, 10 and 20 ppm of alumina nanoparticles was developed to investigate its effects on environment and human health. Nanoparticles caused reductions in the emissions of CO_2, CO and PM emissions compared to biodiesel and diesel fuels when compared to the combustion of blend without additive. The increase in most of the impact categories such as acidification, eutrophication and marine eco-toxicity was observed during combustion. This can be attributed to the increasing emissions of NOx and the toxic effect related to the synthesis of the nanoparticles when compared to combustion without nano additive [13].

This work aims to study the effect of alumina nanoparticles (average size of 10±2 nm)with concentrations of 20, 30 and 40 ppm added to diesel- biodiesel jatropha B20 which it is the most recommended value to use blended biodiesel on engine performance and exhaust emissions. Effect of addition of alumina nanoparticles to biodiesel jatropha on engine performance, exhaust emissions and combustion characteristics compared to biodiesel and diesel fuels.

II. MATERIALS AND METHODS

A. Properties of Nanoparticles

Nanotech Egypt Company supplies the alumina nanoparticles with average size of 10±2 nm with 99% purity, with detailed specifications list in Table 1. The size of the nanoparticles is very important in nano composites to evaluate the mechanical and chemical properties. The structure and morphological characterization of aluminum oxide nanoparticles was carried out using Scanning Electron Microscopy (Model: Quanta FEG250) and Transmission Electron Microscope (Model: JOEL JEM-2100) in Central laboratories, National Research Centre, Egypt. The SEM images showed that, most of the nanoparticles obtained from all the abated laser energies have spherical shape with a particle size of 10±2 nm as shown in Fig.1.

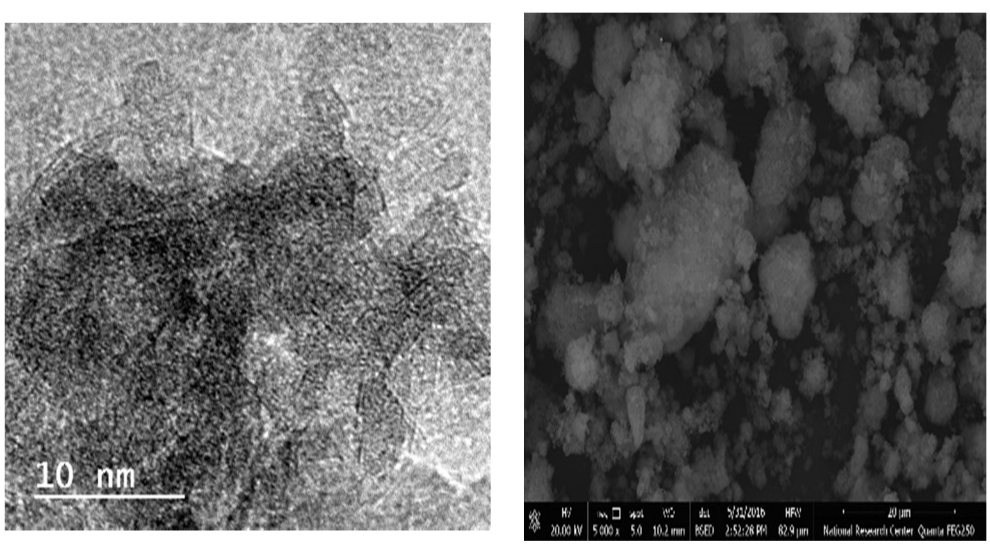

Fig.1. SEM and TEM images of Alumina nanoparticle.

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Table 1: Specifications of alumina nanoparticles

Item	Specifications
Manufacturer	Nanotech company, Egypt
Chemical name	Gamma Aluminum Oxide (Alumina, Al_2O_3)
	Nano powder, Gamma phase, 99.9%
Appearance	White
Average particle size	10 ±2 nm
BET surface area (SSA)	>150m^2/g
Appearance	White
Melting point	2045 ºC
Boiling point	2980 ºC
Density	3.9 g/cm^3
Molecular weight	101.96

B. Preparation of Fuel Blends

1) Jatropha biodiesel preparation The transesterification process can accomplish the conversion of Jatropha oil into its methyl ester. Transesterification involves reaction of the triglycerides of Jatropha oil with methyl alcohol in the presence of a catalyst Sodium Hydroxide (NaOH) to produce glycerol and fatty acid ester. Because of high Free Fatty Acid (FFA) content for Jatropha oil a two stage transesterification process which includes an acid catalyzed transesterification followed by a base catalyzed tranesterification was carried out[14-16].The production of biodiesel by transesterification of the oil generally occurs using the following stages The first stage of the process is called esterification, and this is used to reduce the free fatty acid (FFA) content in Jatropha oil with methanol (99% pure) and acid catalyst (sulfuric acid-98% pure) in three hours reaction at 80ºC. 3% by weight of sulfuric acid is to be added to oil. Esterification process reduces the tendency of oil to make soap. In the second stage, called transesterification, Jatropha oil is heated up to 70 ºC in a round bottom flask to drive off moisture and stirred vigorously. The triglyceride portion of the Jatropha oil reacts with methanol having density 0.791 g/cm³ and base catalyst (potassium hydroxide - 99% pure), which is dissolved in Methanol in molar ratio 6:1 in a separate vessel and was poured into round bottom flask while stirring the mixture continuously.The alkaline catalyst concentration in the range of 0.5 to 1% by weight yields 94 to 99% conversion of vegetable oil into esters. The mixture is maintained at atmospheric pressure and 65°C for 60 minutes to form an ester and glycerol. In this process, the triglyceride is converted stepwise to diglyceride, monoglyceride, and finally glycerol. After completion of transesterification process, the mixture is allowed to settle under gravity for 24 hours in a separating funnel. The products formed during transesterification were Jatropha oil methyl ester and Glycerin. The bottom layer consists of Glycerin, excess alcohol, catalyst, impurities and traces of unreacted oil. The upper layer consists of biodiesel, alcohol and some soap. The glycerol layer was separated and the raw fatty acid methyl ester (FAME) was water washed to remove unreacted methoxide, unreacted methanol and catalyst by the process of water washing with air-bubbling. It was then heated to remove the water traces to obtain clear biodiesel. This process resulted in 92% yield of the methyl esters. The measurements of fuel properties of Jatropha biodiesel and its blend with biodiesel B20 in comparison with that of diesel fuel according to ASTM D 6751-02 [17] are shown in Table 2.
2) Dispersion of Alumina Nano Particles (AL_2O_3) The Alumina nanoparticles of average size of 10±2 nm were dispersed into a mixture of jatropha biodiesel-diesel fuel (B20) at the recommended composition (20 % by volume of Jatropha Methyl Ester (JME) and 80 % of diesel fuel). Three types of tested fuels were prepared by dispersing alumina nanoparticles in mass fraction forming 20, 30, and 40 ppm with Jatropha biodiesel. Nanoparticles have higher surface contact area and surface energy. Nano aluminum oxide particles were clustered together to form micro molecule and start to sediment. Nano particlesare needed to surface modification to be steady in the fuel. Ultrasonication process is the best method to disperse the nanoparticles in the fluid to prevent the agglomeration of nanoparticles using pulsating frequencies to disperse nanometer ranges into the fluid. A constant agitation time of 30 minutes was applied to produce uniform suspension. The fuel with nano additives should be used immediately after preparation to avoid any settling or for sedimentation of nanoparticles [8, 9, 18, 19, 20, 21, 22, 23, 24, 25].For the preparation of B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO test fuels, concentrations of 20, 30 and 40 ppm of alumina nanoparticle were blended with 1 liter of Jatropha Biodiesel (B20) separately and dispersed using ultrasonicator apparatus (Model: UD50SH-2.5LQ) set at 40kHz frequency. The surfactants Span80 and Tween80 were used in dispersing

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alumina nanoparticles in jatropha biodiesel for better stability. The prepared alumina nano fluids were evaluated for their stability by different characterization techniques such as sedimentation, TEM, and by UV-Vis spectroscopy.Before the start of the experiment, all the prepared Nano fluids were kept in graduated test tubes without disturbing them and periodically the stability characteristic tests were carried out for the test fuels and found stable for 10 days without any phase separation. The test fuels were subjected to stability test and found stable for 10 days without phase separation for agitation time of 30 min. Figure 2 shows the photographic images of the stable nanofluids of alumina nanoparticles (~10 nm) dispersed in jatropha biodiesel having 30 ppm volume fractions for different stability time durations for one month older. Fig. 3 showed the Transmission Electron Microscopy (TEM) images and UV-Vis spectroscopy of the alumina nanoparticles (having average size ~10±2 nm) dispersed in the Jatropha biodiesel having 30 ppm for 10 days. TEM images confirm the dispersion stability of alumina nanoparticles in Jatropha biodiesel as the base fluids for as-prepared samples, which is further confirmed from the UV-Vis spectroscopy. UV–Vis spectrum was used to evaluate the nanofluid stability. Absorption was plotted against nanoparticles wavelength. It is found that maximum absorbency is occurred in the wavelength of 222 nm. By increasing the wavelength, UV absorption increases until maximum wavelength of 222 nm, after that there was a decrease in absorption.

(a)Jatropha biodiesel B20 (b) prepared sample (c) Ten days

Fig.2. Photographic Stability images of Alumina nanoparticles of 30 ppm volume fraction(a) jatropha biodiesel B20, (b) prepared sample and (c) Ten days sample.

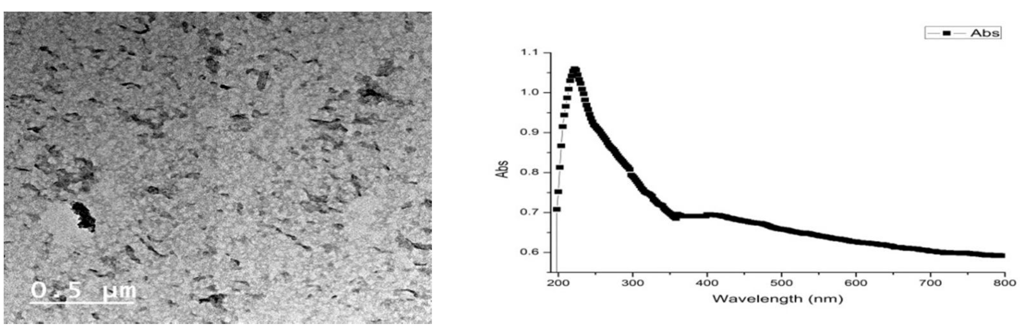

Fig.3. TEM micrographs and UV-Vis spectroscopy of 10±2 nm Nano-particles of 30 ppm volume fraction with 10 days stability time.

Table 2: properties of diesel fuel, B100 and B20

Properties	Method	diesel	B100	B20
Kinematic viscosity, at 40ºC cSt	ASTMD4454.5	5.6	5.2	
Heating value MJ/kg	ASTMD270	42.73	39.52	41.45
Density, at 15ºC kg/m^3	ASTMD1298	825	875	845
Cetane number	ASTMD613	50	58	53
Flash point ºC	ASTMD92	77	164	88
Pour point ºC	ASTMD97	-17	-8	-----
Cloud point ºC	ASTMD97	-12	-4	------

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III. EXPERIMENTAL SET UP

A. Engine Setup

The experimental program was carried out using a single cylinder, four stroke, air cooled, direct injection (DI), naturally aspirated, constant compression ratio, diesel engine with a developing power of 5.775 kW at 1500 rpm at Mechanical Engineering department, National Research Centre, Egypt**.** The technical specifications of the engine are given in Table 2, and the schematic diagram of the experimental arrangement is shown in Fig. 4. AC generator of maximum electric power output of 10.5 kW equipped with a load controller and other auxiliary items have been coupled directly to the test engine to determine the engine brake power. The intake airflow was measured by a sharp edged orifice mounted in the side of an air box, coupled to the engine inlet to dampen the pulsating airflow into the engine. A U tube manometer was used to measure the pressure drop across the orifice. Calibrated thermocouple probes of type (K) were used for temperature measurements at different locations in the experimental set up; including: intake air manifold and exhaust gas. A selecting switch is used to switch among these thermocouples and the signals are readout by a digital thermometer. The crankshaft rotational speed was measured using speed tachometer. Two fuel tanks of 10 Liters capacity were mounted for storing the fuels on the rear side of the panel at highest position. One burette with stopcock and two way valves was mounted on the front side of the panel for fuel flow measurements and selecting between both diesel and biodiesel fuels. The fuel consumption was determined by measuring the time for the consumption of fixed fuel volume (20 ml). For recording, the instantaneous in cylinder pressure a water cooled Kistler piezoelectric pressure transducer (model 601A) measure from 0 to 250 bar as pressure range with sensitivity of 16.5 pc/bar and accuracy of 1.118% connected with Nexus charge amplifier (2692-A-0S4) were used. The piezoelectric pressure transducer was flush mounted with the cylinder head to measure the combustion pressure. The flush mounting was preferred to minimize the lag in the pressure signal and avoid pipe connecting passage resonance. The instantaneous position of the piston top dead center (TDC) was determined using a proximity switch (Type LM12-3004NA) fixed on the output shaft of the engine. In order to guarantee confidence in the combustion diagnosis results, the combustion pressure data were averaged over 120 consecutive engine cycles.

In all the cases, the pressure crank angle diagrams were recorded and processed, to get the combustion parameters by the data acquisition system. High speed data was acquired using LABVIEW software and national instruments data acquisition system (NI-USB-6210) for later analysis. OPA 100 smoke meter and MRU DELTA 1600-V Gas Analyzer were used for the measurements of various exhaust gas parameters. The accuracy and reproducibility of the instrument was ±1% of full scale reading. The measurement principle for CO, HC, CO_2 was infrared measurement and for NO and O_2 it was electrochemical measurement. Digital readouts of CO and NO_X, HC, CO_2 and O_2 are available through the analyzer screen after steady state conditions and the average was taken for fifth minutes. Tests were executed without carrying out any modification on the engine or its fuel injection system (mass injected or injection timing). The experiment was carried out by varying load from zero to full load by maintaining constant speed of 1500 rpm throughout the experiment. The injection timing was 24º BTDC at an injection pressure of 175 bar and compression ratio was 17.5:1. The engine trial was conducted as specified by IS 10,000. In each test, the performance and emission measurements were triplicated. All the equipment's were calibrated in accordance to the respective manufacturer's specifications, prior to conducting the tests. All the tests are carried out for three times under steady state condition and the observed uncertainties for NO, unburned HC, CO, Smoke opacity and BTE are ±1 ppm, ±1 ppm, ±0.01 % Vol, ± 1 % and ± 1.5 % respectively. The maximum uncertainty in measurement of brake power, brake specific fuel consumption, and engine speed are found to be 0.85 %, 2.2 % and 0.15 % (± 2 rpm), respectively. At the end of the test, the engine is made to run with neat diesel to blush out the nanoparticles-blended diesel fuels from the fuel line systems.

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Table 3: Engine specifications

Engine parameters	Specifications
Type	DEUTZ F1L511
Number of cylinders	1
Number of Cycles	Four stroke
Cooling type	Air cooled
Bore (mm)	100
Stroke (mm)	105
Compression ratio	17.5:1
Fuel injection advance angle	24º BTDC
Rated brake power (kW)	5.775 at 1500 rpm
Number of nozzle holes	1
Injector opening pressure (bar)	175

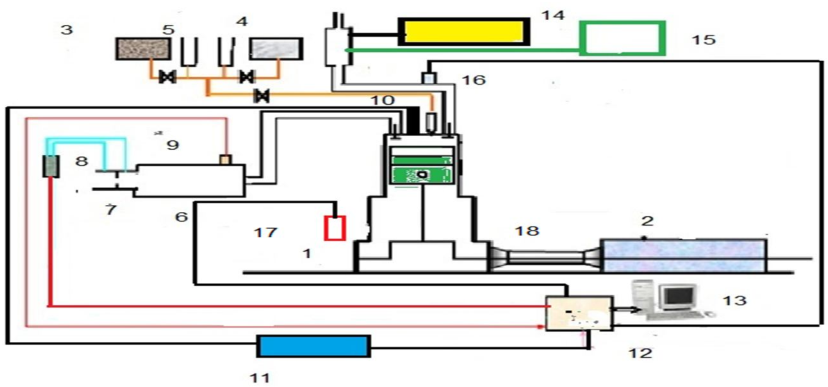

Fig. 4 Schematic diagram of the experimental setup.

1- Diesel engine
2- AC generator
3- Diesel tank
4- Biodiesel tank
5- Burette
6- Air surge tank
7- Orifice
8- Pressure differential meter
Intake air temperature thermocouple
10- Piezo pressure trnsducer
11- Charge amplifier
12- Data acquisition card
13- Personal computer
14- Exhaust gas analyzer
15- Smoke meter
16- Exhaust gas temperature thermocouple
17- Proximity switch
18- Cardan shaft

B. *Experimental Error Analysis*

The details of the instrumentation adopted in the present investigation are presented in Table 4. The overall uncertainty of the experiment was calculated by the addition of the uncertainties of the individual instruments, and is given as follows.

Total percentage uncertainty of this experiment is=

Square root of {(uncertainty of exhaust gas temperature)^2 + (uncertainty of brake power)^2 +(uncertainty of specific fuel consumption)^2 + (uncertainty of engine speed)^2 + (uncertainty of brake thermal efficiency)^2 + (uncertainty of CO emission)^2 + (uncertainty of HC emission)^2 + (uncertainty of NO emission)^2 + (uncertainty of pressure transducer)^2 + (uncertainty of proximity switch)^2}

$= ((0.2)^2 + (0.2)^2 + (0.2)^2 + (0.65)^2 + (0.2)^2 + (0.2)^2 + (0.2)^2 + (0.2)^2 + (0.65)^2 + (0.1)^2)^{0.5} = 1.04$

Using the calculation procedure, the total uncertainty for the whole experiment is obtained to be ±1.04

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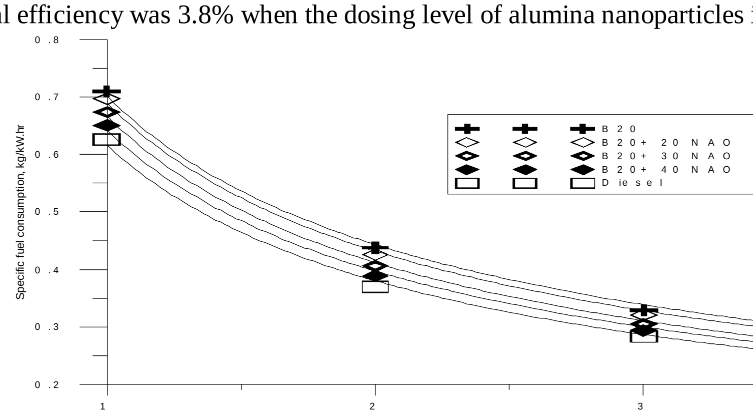
Table 4: Ranges, accuracy and uncertainty of the instruments.

S.No	Instrument	Range	Resolution	Uncertainty
1	Load indicator	250-5000 W	10 W	0.2
	Time of fuel consumption	1-350 sec	1 sec	0.28
2	Exhaust Temperature Thermocouple	0-1300 K	1°C	0.2
3	Burette	1-20 cc	0.1 cc	0.5
4	Exhaust gas analyzer	Smoke opacity (1-100%)	0.1%	0.1
		NO (1-4000 ppm)	1 ppm	0.2
		HC (1-2000 ppm)	1 ppm	0.2
		CO (1-20%)	0.01%	0.2
5	Pressure transducer	1-250 bar	0.05 bar	0.05
6	Engine speed	200-8000 rpm	10 rpm	0.65
7	Proximity switch	0-5 volt	0.1 volt	0.1

IV. RESULTS AND DISCUSSION

A. *Engine Performance Characteristics*

1) *Brake Specific Fuel Consumption (BSFC):* The variation of brake specific fuel consumption (BSFC) for test fuels with respect to engine load is shown in Fig. 3.Lower brake specific fuel consumption are observed for biodiesel-diesel mixture (B20) compared to neat diesel fuel, due to its lower heating value and higher density nature of the biodiesel causing poor atomization. The observed value of BSFC for neat diesel fuel, B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO are 0.24, 0.288, 0.277, 0.26 and 0.252 kg/kW.hr, respectively at full load. The brake specific fuel consumption of all the nano additives tested fuels used in the experiments was observed to be better compared with B20 operation at higher loads. The BSFC reduces with an increase in dosing level of nanoparticles. The decrease in brake specific fuel consumption could be possibly attributed to the effect of nanoparticles on physical properties of the fuel and reduction of ignition delay time moreover the presence of nanoparticles in the blend as it possess enhanced surface area-volume ratio for better catalytic effect, better combustion and less fuel consumption [19, 21, 26, 27, 28,29, 30].There were increases in specific fuel consumption for B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO about diesel fuel. A maximum decrease of 12.5% in BSFC was obtained when the dosing level of alumina nanoparticles is 40 ppm compared to B20 at full load. The maximum increase in BSFC was 5% when the dosing level of alumina nanoparticles is 40 ppm compared to diesel fuel.
2) *Brake Thermal Efficiency (BTE):* Figure 3 illustrates the variation of the brake thermal efficiency against engine brake power. The addition of nanoparticles (aluminum oxide) led to an improvement in brake thermal efficiency compared to biodiesel blend at full load and the improvement increased with the dosing level of alumina nanoparticles. Due to the enhanced surface area to volume ratio by the catalytic effect during the combustion inside the engine cylinder of nanoparticle, resulting in fine atomization and rapid evaporation of fuel, which in turn allows more amount of fuel to react with the air leading to promoting improved brake thermal efficiency [20, 26, 29, 30]. All nano particles additives used in the experiment have high brake thermal efficiency when compared with diesel- biodiesel blend. A maximum increase of 12% in the brake thermal efficiency was obtained when the dosing level of alumina nanoparticles is 40 ppm compared to B20 biodiesel blend at full load. There were decreases in thermal efficiency for B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO about diesel fuel. The maximum decrease in thermal efficiency was 3.8% when the dosing level of alumina nanoparticles is 40 ppm compared to diesel fuel.



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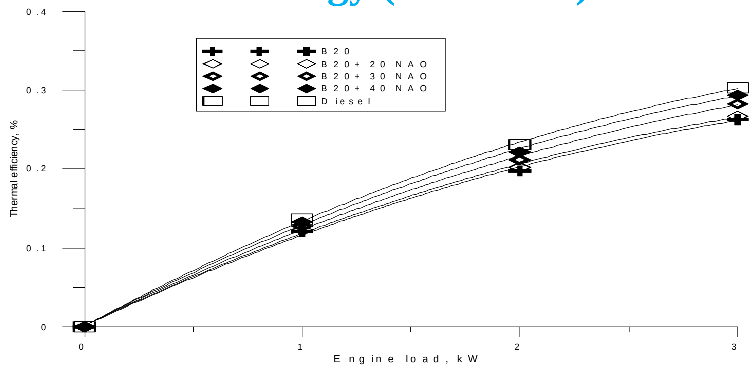
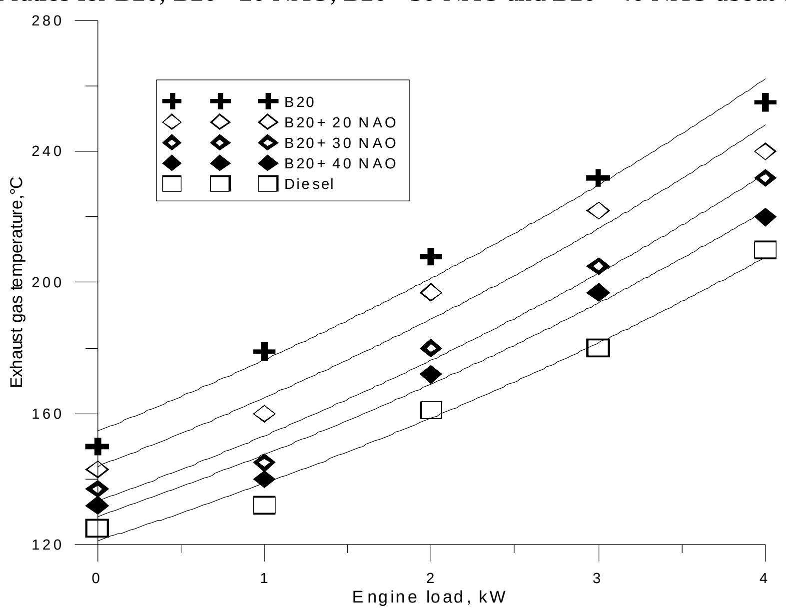


Fig. 3 Variation of brake specific fuel consumption and brake thermal efficiency with engine brake power.

3) *Exhaust Gas Temperature:* Figure 4 shows the variation of exhaust gas temperature with engine load for various test fuels and diesel. The results show that the exhaust gas temperature increases with increase in brake power for all fuels. At all engine loads, diesel was found to have the lowest exhaust gas temperature compared to B20 and fuel with nano additives. Biodiesel being an oxygenated fuel ameliorates the rate of oxidation during combustion and results in high local temperatures and hence the exhaust gas temperatures are higher. The exhaust gas temperatures for alumina oxide nanoparticles blends were lower than that of B20 due to reduction of radiation losses, higher heat transfer coefficient and cylinder temperature, so, the exhaust gas temperature was reduced [18, 26]. It is due to its rapid evaporation rate that leads to better combustion, which in turn results in reduced energy loss in exhaust. The values of exhaust gas temperatures of diesel, B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO were 210, 255, 240, 230 and 220°C at full load. Percentage reductions of exhaust gas temperature for B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO were 5.5, 9.5 and 13 % respectively, when compared with B20 at full load. There were increases in exhaust gas temperatures for B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO about diesel fuel. The increase in exhaust gas temperature of B20+ 40 NAO was about 4.5% compared to neat diesel fuel at full load.
4) *Air Fuel Ratio:* A constant air flow rate is supplied into engine cylinder and so air-fuel (A/F) ratio changes based on mass of the injected fuel per cycle. As shown in Fig. 4, air- fuel ratio was decreased with the increase of engine load due to the increase of injected fuel mass per cycle. Air-fuel ratio increased with increase of alumina nanoparticles in biodiesel jatropha B20 compared to biodiesel blend B20 due to reductions of fuel consumption. Dosing level of 20, 30 and 40 ppm Al_2O_3 nanoparticles additives to biodiesel B20 showed maximum increase in air- fuel ratio of 4, 9.5 and 14% as compared to biodiesel jatropha B20.There were increases in air- fuel ratios for B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO about diesel fuel.



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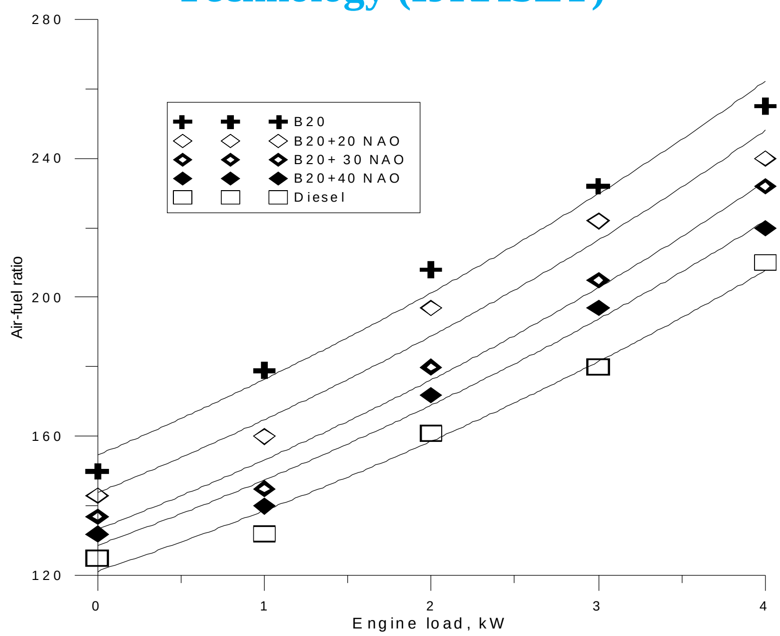

Fig. 4: Variation of exhaust gas temperature and air fuel ratio with engine brake power.

B. *Engine Exhaust Emissions*

1) *Nitrogen Oxides Emissions (NO_X):* The variation of NO_x emission for different blends is indicated in Fig. 5. According to Zeldovich mechanism, the formation of NO_X depends on temperature, residence time and O_2 concentration. NOx emission for diesel and all the blends followed an increasing trend with respect to engine load. The effect of oxygen contents in biodiesel led to the formation of active radicals as OH. These radicals will be used for the formation of NO_x that will be frozen when it leaves the reaction zone.NO_X emissions were found to be mostly increased on the addition of alumina oxides nanoparticles to blends at all engine loads when compared to diesel fuel. Addition of nanoparticles to tested fuels will proceed the reactions to be completed with the least thermal break down of hydrocarbon. Lower active radicals lower the possibility to form thermal NO_x and led to production of NO_x emission [18, 20, 26]. The maximum increase of NO_X emission was 5.5% in case of B20+ 40 NAO compared to neat diesel fuel. The NO_X emission was found to be mostly reduced on the addition of alumina oxides nanoparticles to blends at all loads when compared to biodiesel blend B20. This is due to the shortened ignition delay and less fuel is added during combustion, which in turn, leads to decrease in NO_X emissions [1]. Decrease of NO_X emissions for B20 with nanoparticles was due to the scavenging ofnitric oxide radical by the effect of nanoparticle and responsible for the formation of NO [9].The observed NOx emission for neat diesel, jatropha biodiesel-diesel blend B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO at full load were217, 272, 250, 240 and 230ppm, respectively. The percentage reductions of NOx emission for B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO were 7.5, 10 and 13%,respectively, when compared to that of B20. There were increases in NOx emissions for B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO about diesel fuel. Increase in NOx emission of B20+ 40 NAO about diesel fuel was about 5%.
2) *Variation of Smoke Opacity:* The variation of smoke opacity with respect to engine brake power is shown in Fig.5. It was observed that the smoke opacity of the exhaust gas increases with increase in engine load for all the blends due to increase of fuel consumption. It also showed that the smoke opacity decreased with jatropha biodiesel blend B20 compared to diesel fuel. This is caused mainly due to higher cetane number and oxygen content of biodiesel which led to better combustion and reduction in smoke opacity. The opacity of jatropha biodiesel blend and the nanoparticles blended fuels showed a similar trend patterns as that of diesel fuel, moreover its values were comparatively lower at all engine loads. The observed smoke opacity values for neat diesel, B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAOwere63, 55, 52, 49 and 44% as shown in figure 5 with percentage reduction of 12, 15, 17and 21 % compared with diesel fuel respectively at full load. Significant reduction in smoke opacity was observed in the case of alumina nanoparticles blended jatropha biodiesel-diesel fuels. Reduction in smoke opacity in the case of alumina nanoparticles blended jatropha biodiesel-diesel B20+ 40 NAO was 20% compared to biodiesel blend B20.Reduction in smoke opacity was due to the fast evaporation rate, short ignition delay and improved ignition characteristics of the of alumina nanoparticles resulting in lower smoke emissions compared to that of B20 and diesel fuel [1, 9,

18,20, 31].

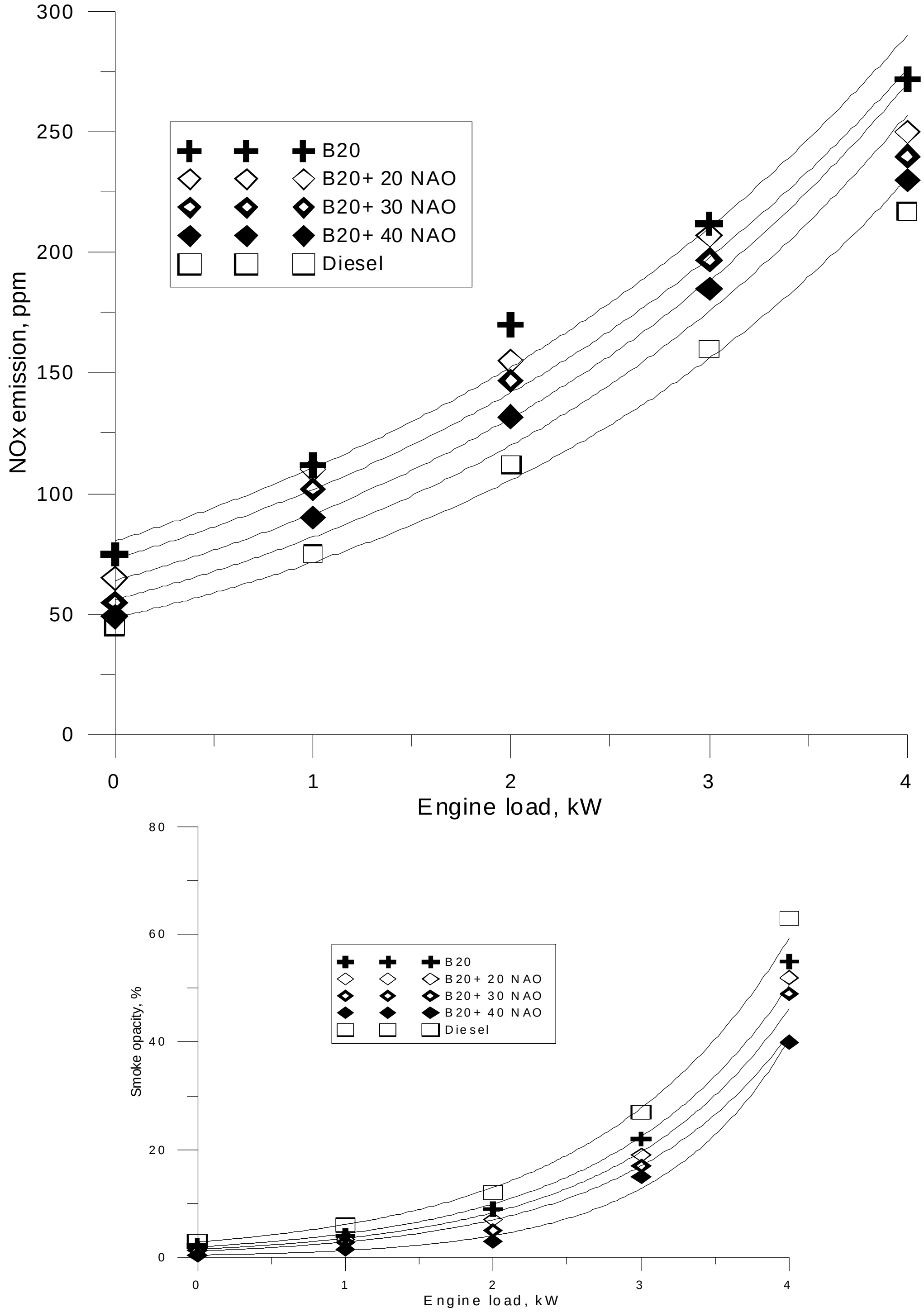

Fig.5: Variation of nitrogen oxides and smoke opacity with respect to brake power

3) *Variation of Carbon Monoxide and Unburned Hydrocarbon:* Figure **6** illustrates the effect of test fuels on Unburned HC and CO under engine load. Unburned HC are formed by incomplete combustion of fuel mainly due to the formation of lean charge during the delay period [32]. The observed values of Unburned HC emission for neat diesel, B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO were 22, 18, 17, 15 and 13 ppm, respectively and the percentage reduction of unburned HC were17, 22, 27 and 32 % compared with neat diesel fuelin average at all loads. Addition of nano alumina led to biodiesel jatropha B20

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led to reductions in HC emissions compared to B20.Addition of nano alumina led to biodiesel jatropha B20+ 40 NAO led to reduction in HC emissions of 29% compared to B20. CO emission is formed mainly due to incomplete combustion of fuel and by insufficient supply of air during combustion [20, 26, 29, 33, 34]. The observed CO emission for neat diesel fuel, B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO are 0.04, 0.038, 0.037, 0.036 and 0.034 byvolume percentage, respectively and the percentage reduction are 5, 7.5, 10 and 12% when compared with neat diesel fuel respectively. Addition of nano alumina led to biodiesel B20 led to reductions in CO emissions compared to B20.Addition of nano alumina led to biodiesel jatropha B20+ 40 NAO led to reduction in CO emissions of 10% compared to B20. Lower CO and HC emissions were observed for jatropha biodiesel (B20) when compared with neat diesel, due to its rich oxygen content that helps to burn the charge completely. Moreover, addition of nanoparticle to biodiesel acts as an oxidation catalyst and enhances the hydrocarbon oxidation in addition to the improved ignition characteristics of alumina nanoparticles and short ignition delay that lead to minimizing unburned HC and CO emission [18, 20, 26,35, 36].

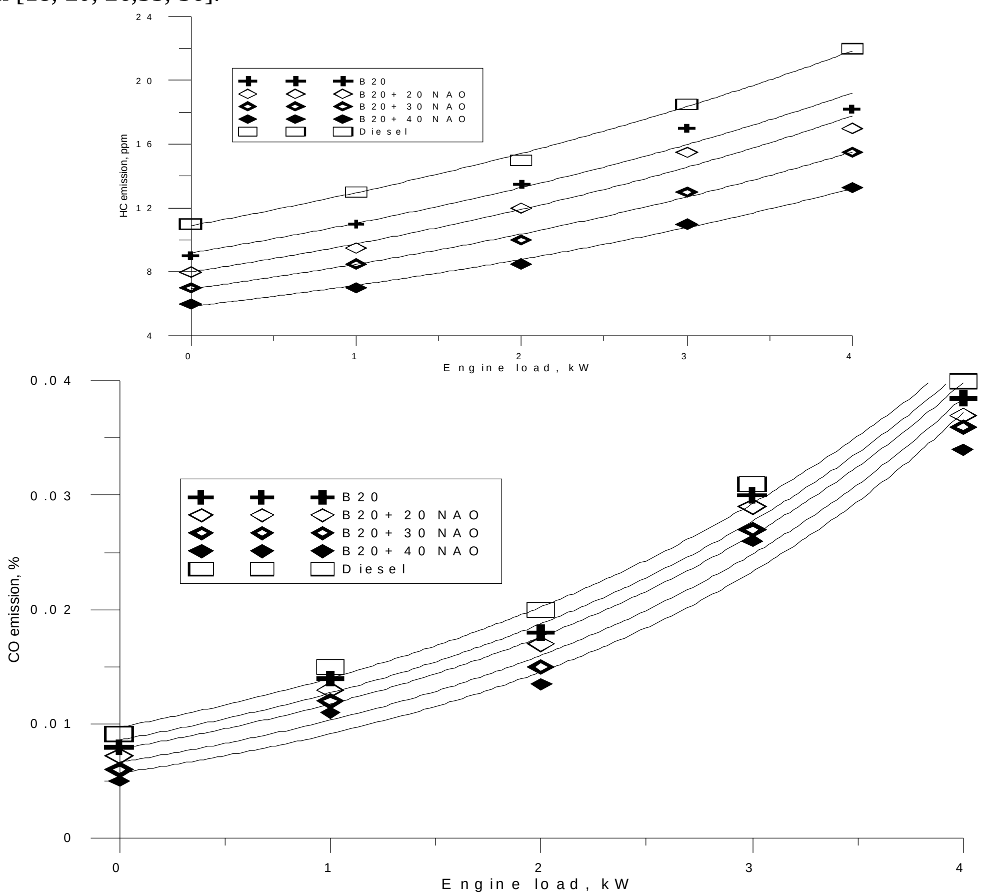

Fig 6 Variation of carbon monoxide and unburned hydrocarbon with brake power

C. *Engine Performance Characteristics*

1) *Variation of Cylinder Pressure and Heat Release Rate:* Variation of cylinder pressure and heat release rate with respect to crank angle for all test fuels at full load is shown in Fig.7. It was observed that all test fuels followed a cylinder pressure and heat release rate pattern similar to the diesel fuel. Lower cylinder pressure and heat release rate were observed for jatropha biodiesel blend with diesel (B20) compared to neat diesel fuel due to the rich oxygen content of biodiesel causing sudden burning of fuel during the uncontrolled combustion phase and reduction of biodiesel heating value compared to diesel fuel. Heat release rate in premixed combustion phase depends on ignition delay, mixture formation and the combustion rate in the initial stages of combustion. Shorter ignition delay caused the air-fuel mixture to accumulate in the combustion chamber. More quantity of fuel is burnt in the premixed combustion phase [5, 18, 20, 26, 29].It was observed that heat release rate and cylinder gas pressure characteristics were higher for the alumina oxide nanoparticle blended fuels (B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO) compared to biodiesel blend B20. This is could be due to accelerated combustion due to the shortened ignition delay, improved

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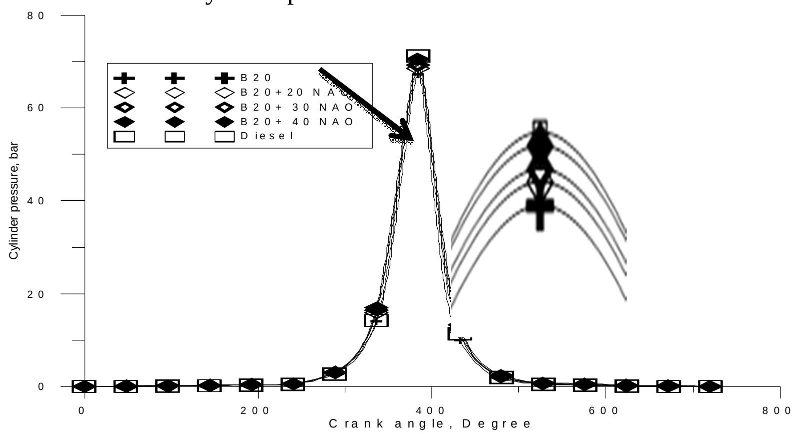
atomization, rapid evaporation of fuel, the degree of fuel mixing and uniform burning could have improved [11, 26,37, 38]. Increase in the ignition delay period had bad effects in fuel atomization and evaporation. Nano additives have an effect on the heat transfer rate during fuel atomization and evaporation, the start of the combustion process in cylinder was remarkably advanced. Addition of the alumina nanoparticles improved the reaction rate, the heat was liberated during shorter ignition delay, improved combustion and higher values of the peak cylinder pressures and heat release [18, 26].Heat release rate and cylinder gas pressure characteristics were lower for B20, B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO compared to diesel fuel. From the figure, it was seen that the cylinder peak pressures for diesel fuel and biodiesel blend B20 were71.22 and 67.2 bar were attained at a crank angle of 4° after TDC. In case of B20+ 20 NAO, the cylinder peak pressure of 68.5 bar was achieved at crank angle of 3° after TDC. In case of B20+ 30 NAO the cylinder peak pressure of 69.2 bar was achieved at crank angle of 2° after TDC. In case of B20+ 40 NAO the cylinder peak pressure of 70.2 bar was achieved at crank angle of 2° after TDC. The amount of heat release rate for B20, B20+ 20 NAO, B20+ 30 NAO, B20+ 40 NAO and neat diesel were37.03, 37.3, 38.1, 38.8 and 39.1 kJ/Degree, respectively. Whereas increasing the dosing level of aluminum oxide nanoparticles in biodiesel blend B20 tended to increase the heat release rate and cylinder pressure.



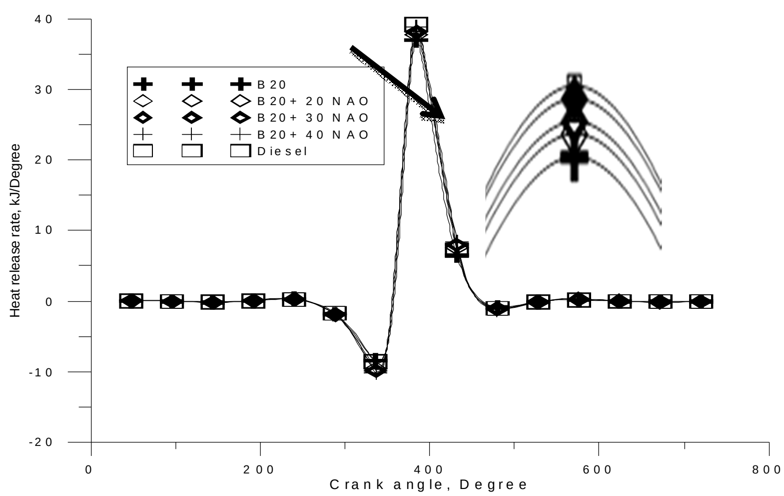


Fig 7 Variation of cylinder pressure and heat release with crank angle at full load.

2) *Variation of Cylinder Peak Pressure:* Variation of peak cylinder pressure with engine brake power is shown in Fig.8. For different fuels, the values of peak cylinder pressure were increased with the increase of engine load due to the increase of injected fuel mass that results in increasing the amount of heat released. Higher heat release rate and cylinder pressure characteristics were observed for the nanoparticle blended test fuels B20+ 20 NAO, B20+ 30 NAO and B20+ 40 NAO compared to biodiesel blend B20 which was due to the advancement of combustion phase by improved atomization and rapid evaporation of fuel [18, 26,39, 40]. That cause decreased peak cylinder pressure for blended fuels compared to neat diesel fuel at all engine load range. At full load, the values of peak cylinder pressure were 67.2, 68.5, 69.2, 70.5 and 71.22 bar for B20, B20+ 20 NAO, B20+ 30 NAO, B20+ 40 NAO and diesel fuels.

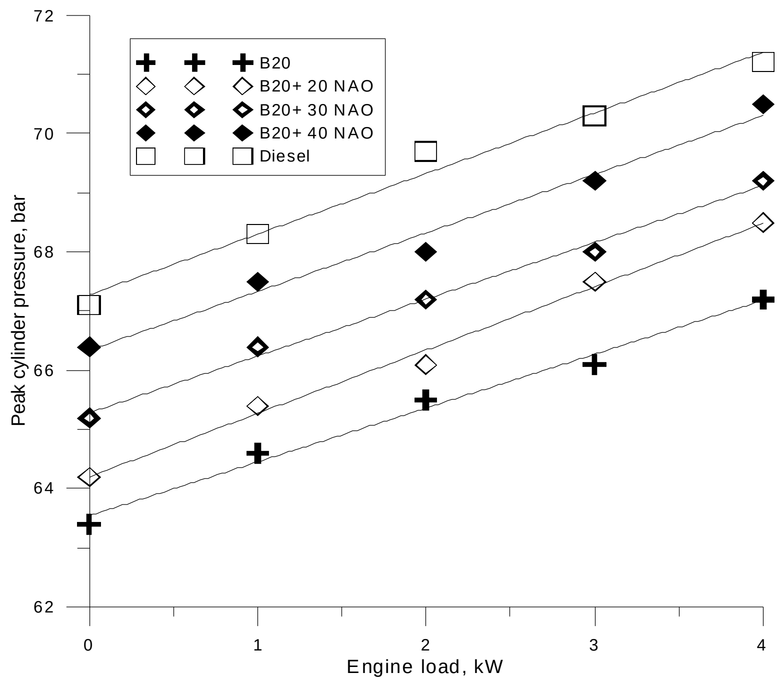


Fig.8. Variation of peak cylinder pressure with engine brake power.

V. CONCLUSIONS

Performance, exhaust emission and combustion characteristics of diesel engine use jatropha biodiesel-diesel fuel mixture (with/without addition of alumina nanoparticles) were investigated by experimental work at various engine loads. The major conclusions of this investigation include:

A. The use of nano-additives of alumina not only improves the performance of diesel engine, but also reduces the exhaust emission level of all pollutants (smoke opacity, UHC and CO) in the exhaust gaseous due to its catalytic effect on the fuel combustion process, especially in comparison with the effect of jatropha biodiesel-diesel mixture.

B. Considerable improvement in brake thermal efficiency and reduction of specific fuel consumption were attained with Al_2O_3 added blends compared to that with B20 at full load operating conditions. Due to its high surface area to volume ratio of nanoparticle promoting better combustion by improved atomization, better mixing of air-mixture and rapid evaporation of the fuel.

C. There were maximum decrease of 12.5% in BSFC and maximum increase of 12% in the brake thermal efficiency were obtained when the dosing level of alumina nanoparticles is 40 ppm compared to B20 at full load. Maximum percentage reduction of exhaust gas temperature for B20+ 40 NAO was 13 % when compared with B20 at full load

D. With the addition of nanoparticles to B20 fuel, the level of harmful pollutants in the exhaust gases, such as HC, CO and smoke, was significantly reduced when compared to that of neat diesel. At the dosage of 40 ppm alumina nanoparticles blends, the smoke opacity reduced by 20 %, unburned hydrocarbon by 10 % and carbon monoxide by 29% compared to B20 at full load operating conditions.

E. The percentage reduction of NOx emission for Al_2O_3 added blends B20+20 NAO, B20+ 30 NAO and B20+40 NAO compared to that with B20 at full load operating conditions are 7.5, 10 and 13%, respectively. However, the maximum increase of NO_X emission was 5% for 40 ppm dosing level of Al_2O_3 nanoparticles added blends compared to neat diesel fuel.

F. The peak cylinder gas pressures and heat release rates when conventional fuel was used at rated power was higher than that of B20 with and without addition of AL_2O_3nanoparticles.

G. A dosing level of alumina nanoparticles in the range of 40 ppm is recommended to achieve the best engine performance with optimal emissions reductions and combustion characteristics, particularly to remove the disadvantages related to use of biodiesel blends into diesel fuel.

H. Jatropha biodiesel blend with diesel fuels (B20) with alumina nanoparticles additive are suitable alternative fuels for diesel engines without major change in engine hardware.

I. The results indicated that there is a need to carry further research on the use of Nano additives in higher concentrations in biofuels than those studied in this paper. Such information would allow determining whether the typical emissions from the combustion of fuel blend increase when the concentration of nanoparticles is varied. Verify its impact in human health and the renewability of these alternatives regarding the sustainability of the process.

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NOMENCLATURE

A/F	Air/fuel mass ratio, kg of air/kg of fuel
BTDC	Before top dead center
BSFC	Brake specific fuel consumption, kg/kW h
BP	Brake power, kW
C.A.	Crank angle, Degree
CO	Carbon monoxide, %
AO	Alumina-nanoparticle with mass fraction 20 ppm mixed with Jatropha biodiesel blend
AO	Alumina-nanoparticle with mass fraction 30 ppm wmixed with Jatropha biodiesel blend
AO	Alumina-nanoparticle with mass fraction 40 ppm with mixed Jatropha biodiesel blend
NO_X	Nitric oxide, ppm
P_{cyl}	In-cylinder pressure, kPa
rpm	Revolution per minute
T_{exh}	Exhaust gas temperature, K
UHC	Unburned hydrocarbons, ppm