Experimental studies on the performance and emission characteristics of compression ignition engine fueled with jatropha and pongamia biodiesel along with Alumina Nano particles

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Abstract ***— In this study an experimental investigation has been carried out on compression ignition engine to understand the engine behaviour with respect to its performance and emission characteristics while using Aluminium oxide (Al_2O_3) Nano particle as additive with a blend of diesel and biodiesel sourced from Jatropha and Pongamia vegetable oils. The Alumina Nano particles are characterized by X- ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) analysis. The biodiesel is made engine ready with adoptable properties by carrying out standard alkali transesterification process. The alumina Nano particles are blended with jatropha in the mass fractions of 50,100,150 ppm and with Pongamia biodiesel in the mass fractions of 40, 60 ppm using an Ultrasonicator. The experiments are carried out in single cylinder four stroke Variable Compression Ratio diesel engine by varying the load using eddy current dynamometer. The experimental results reveal that there is a significant improvement in the performance characteristics like Brake Thermal Efficiency and Brake Specific Fuel Consumption and considerable reduction in the emission constituents like carbon Monoxide (CO) and Unburned Hydrocarbon (HC) but in turn increase in Nitric oxide (NOx) emissions were observed.***

Index Terms— *Diesel engine, Nano additives, Jatropha, Pongamia*

I. INTRODUCTION

The reason why diesel fuel consumed much higher than petrol all over the world is that the diesel powered engines have less fuel consumption, reliability and high brake thermal efficiency due to its high compression ratio operation. But on the other hand, the diesel engine exhaust may become one of the major sources of air pollution in nearby future [1]. Everyday increase in the use of diesel engine powered vehicles increases the pollution and as a result diesel powered vehicles are banned to protect human beings from environmental hazards in major cities across the country. The applications of diesel powered engines increases day by day with respect to population of the country which results in lack of availability of diesel, due to which the prices of diesel fuel are revised very frequently. Also the emission regulations are becoming more stringent as and when it is revised which promotes the researchers to find advancements in use of alternative fuels and concentrate more on emission reduction technologies [2]. The use of alternative fuels like vegetable oil in diesel engine is a former concept which has been tried by the inventor of diesel engine Rudolf diesel [3]. The biofuel powered engine produces less smoke, Carbon monoxide, particulate matter and unburned hydrocarbon emissions; on the other hand, it results in the formation of high flame temperatures inducing more NOx emissions during combustion [4]. The reason behind the usage of biodiesel as alternative fuel by researchers is that it can be fueled directly in diesel engine without any hardware modifications [5]. In addition, biodiesel has more oxygen molecules in its molecular structure, which in turn improves the combustion characteristics of the engine [6]. The use of injecting water into diesel engines is one of the technique to reduce NOx emissions. The water effectively reduces the peak flame temperature by absorbing heat that is released from combustion and thereby helps in reducing NOx emissions [7]. Another method of injecting water into diesel engine is in the form of micrometer/nanometer-sized droplets which improves the combustion of fuels. Since the boiling point of water is less than diesel, water droplets present in the form of small emulsions in diesel fuel starts to vaporize under heated stage of engine. Such vaporization helps in improving the atomization of fuel, better evaporation rate and eventually improves the fuel–air mixing process [8]. Nano emulsion is one of the method of emulsion which is formed by mixing its constituents smoothly. These emulsions are crystal clear and kinetically stable. The particle size in Nano emulsion is less than 100nm which are prepared by using less surfactant concentrations and in micro-emulsions the particle size and surfactant concentration is quite high [9]. The micro-explosion phenomenon of Nano-sized water droplets in the diesel fuel accelerates the fuel evaporation rate and its mixing process with air and eventually helps in reducing the overall combustion duration [10].

Few researchers have used the Nano fluids in automobile engine cooling system increases the efficiency of engine by increasing the heat removal rate from the engine to the atmosphere, Nano particles can be dispersed into conventional coolants [11]. Heat transfer between engine and atmosphere directly affects engine performance, fuel efficiency and emission characteristics. Managing and utilizing the heat generated from the engine combustion is particularly important in improving life of the engine, oil cooling. Nano fluids with improved properties could result in smaller, more efficient vehicles [12]. Nano fluids have excellent physical properties, among which thermal conductivity is one of the primary factor which plays a vital role in enhancing the heat transfer between two mediums. The Nano particles with lubricating oil help in improving the Tribological behavior of the engine. The lubricating oils with Nanoparticle additives exhibit improved load-carrying capacity, anti-wear characteristics. These features about Nano fluids made very attractive in some cooling and lubricating applications of IC engines in commercial and industrial sectors [13]. Nano Particles made of metal oxides can be added to lubricant base fluids as additives, and they are widely used for anti-friction and anti-wear applications. The metal Nano Particles has excellent self-repairing properties and also poses a benefit of being environment friendly [14]. One of the most influencing factors related to properties of Nano fluids is the rate of dispersion and stability of Nanoparticles inside the base fluid. When dispersion of particles inside the base fluid is not good, it results in agglomeration and precipitation of Nanoparticles. The dispersing of Nanotubes inside the base oil is carried out by three mechanical methods like bath and probe ultrasonic and ball-mill methods [15].

Application of Nano scale energetic materials are being increased every day. One of the recent emerging innovation is introducing Nano materials in liquid fuels such as diesel. Such Nano particle helps in improving the properties of diesel, enhances the performance of diesel engine and minimizes the hazardous emission constituents [16]. SonerGumus et al... investigated the synthesis and physicochemical properties of Nano diesel including CuO and Al_2O_3 and they found that the addition of Nano particles in diesel fuel does not cause any much of variations in the physicochemical properties such as the kinematic viscosity, sulfur, density and distillation characteristics, but a slight increase in flash point temperature and cetane index was observed. The pH, type and the concentration of the dispersant are greatly influenced the dispersibility of Nanoparticles in the diesel [17]. Nano fuels in diesel exhibits an increased evaporation rate with early ignition reducing the ignition delay, decreased peak pressure at full load conditions. The performance wise it results in reduction of fuel consumption without losing the energy in terms of brake power, Increased Brake Thermal Efficiency. The emission wise the Nano diesel decreases CO and HC emissions and increases NOx emissions slightly [18].G.Vairamuthu et al investigated the influence of adding cerium oxide Nano particles with Calophyllum inophyllum methyl ester in diesel fuel by varying the nozzle configurations from 3 holes to 5 holes and they found that the reduction in the emission constituents is directly proportional to the dosing level of Nano fluid and Biodiesel and optimum dosing level of Nano particles are found to be 40 ppm [19]. The effect of adding Cerium Oxide and Carbon Nanotubes in Di-esterol fuel blends increases the Brake Thermal efficiency and cylinder gas pressure, advances the occurrence of the peak heat release rate, decreases the ignition delay and as far as emissions are concerned, HC and smoke emissions were reduced, CO emissions were increased and NOx emissions were almost constant [20]. A study carried out with chicken waste fat oil in blend with alumina Nano particle shows that the Brake Thermal Efficiency, peak cylinder pressure and heat release rate increases with increase in Alumina concentration and emission constituents like CO, HC and smoke decreases with slight increase in NO emissions with increase in Biodiesel and Alumina concentration [21].T. Shaafi et al conducted a study on the combustion, engine performance and emission characteristics of CI engine using soybean biodiesel and Alumina Nano additive and they concluded that the cylinder pressure and maximum heat release occurs when the concentration of biodiesel and Nano additive is high. The presence of Alumina particles improves the atomization process and helps in achieving complete combustion, thereby increases the heat transfer from the products of combustion. The emission constituents like CO, CO_2, HC decreases and NOx emission increases by the addition of Alumina Nano particles [22]. The Honge oil methyl ester exhibits poor thermal efficiency and increased emission constituents. But the addition of Graphene, Multi Wall Carbon Nano Tubes and silver Nano particles enhances the combustion characteristics, reduces the emissions and ignition delay during combustion process [23]. Another study conducted on the performance, emission and combustion characteristics in a diesel engine using Jatropha Emulsion fuel and Carbon Nano Tubes as Nano additive exhibits that with an increase in emulsion concentration the Brake Thermal efficiency increases and due to shortened Ignition delay the peak pressure and heat release rate seem to decrease as the Nano additives are blended with Jatropha Methyl Ester. Due to the combined effect of micro explosion and secondary atomization the emission constituents like NOx and smoke are drastically reduced [24]. Sunil Kumar Sharma1 et al conducted a study on performance and emission characteristics of diesel engine fueled with jatropha methyl ester and tyre pyrolysis oil by addition of carbon nanotubes (CNT) and cerium oxide as Nano additive and they concluded that the thermal efficiency increases with increase in Fuel consumption and the emission constituents like CO, HC, smoke and NOx decreases by the addition of Nano additives [25]. A study conducted on engine performance, exhaust emissions and combustion characteristics of a diesel engine using zizipus jujube methyl ester blended fuel along with Aluminium oxide nanoparticles as Nano additive results in higher fuel consumption, Marginal boost of thermal efficiency and decrease of emission constituents like CO, HC and smoke and increase of NOx emissions [26]. C. Syed Aalam et al... Studied the effect of adding Alumina Nano additive with mahua biodiesel and their results exposed an enhancement in thermal efficiency and slight reduction in emission constituents like CO, HC and smoke [27]. An investigation carried out as a motive to reduce the harmful emissions from engine exhaust using cerium oxide on amide-functionalized multiwall carbon nanotubes with Biodiesel blend and they found a considerable reduction in emission constituents like NOx, CO, HC and soot [28]. The present work aims at studying the engine behavior by fueling the diesel with Jatropha and pongamia biodiesel along with varying proportions of Aluminum oxide as Nano additives.

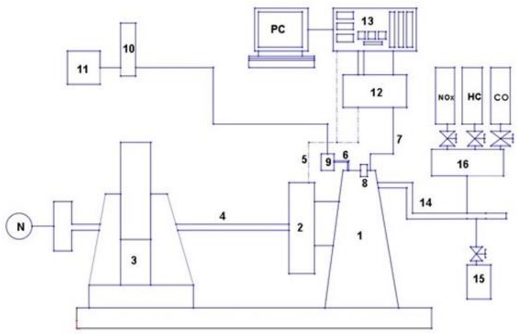
II. ENGINE SET UP

The experimental setup consists of single cylinder four stroke VCR diesel engine. The detailed configuration of the engine used in this study is given in the table I.

TABLE I. ENGINE CONFIGURATIONS

S. No	Types	Specification
1.	Type of Engine	VCR (Variable Compression Ratio) Single Cylinder Multi fuel Research engine
2.	Make & Model	Kirloskar & 240PE
3.	Bore (mm)	87.5 mm
4.	Stroke (mm)	110 mm
5.	Compression ratio	17.5:1
6.	Cubic capacity	0.661 liters
7.	Max. speed	2000 rpm
8.	Fuel timing for Standard engine	23^0 BTDC
9.	Lubricating system	Forced feed system
10.	Type of Loading	Eddy Current Dynamometer

The ENGINE SOFT software is initially configured with input data's like flow rate of air, fuel and cooling water, Calorific Value of the fuel, Density of the fuel and polytrophic index. The performance parameters like BSFC, BTHE, BP, mechanical efficiency are obtained through signals extracted through ECU and stored in the form of tables and plots hard disk. The exhaust emission pipe is connected with four gas analyzer and AVL make smoke meter in order to measure emission constituents like Carbon Monoxide (CO), Unburned Hydrocarbons (HC), NOx, CO_2 and smoke. The graphical view of the experimental setup is shown as layout in figure 1.



1. Cylinder 2. Flywheel 3. Eddy current dynamometer 4. Shaft 5. Crank encoder 6. Inlet manifold 7. Pressure signal line to ECU 8.Pressure sensor 9.Carburettor 10.air tank 11.Fuel tank 12.Data acquisition system 13.ECU 14.Exhaust pipe 15.Smoke meter 16. Exhaust gas analyser

Fig 1. Experimental Layout

III. CHARACTERIZATION OF NANO PARTICLES

The crystalline phase of Alumina Nano particles is determined by X-ray Diffraction and all the peaks obtained are shown in fig 2. Fourier transform infrared (FTIR) spectroscopy of Al_2O_3 Nano Particles was conducted to determine the presence of various functional groups. The FTIR spectra were measured in the wavenumber range of 1000–3500 cm-1 as shown in fig 3.

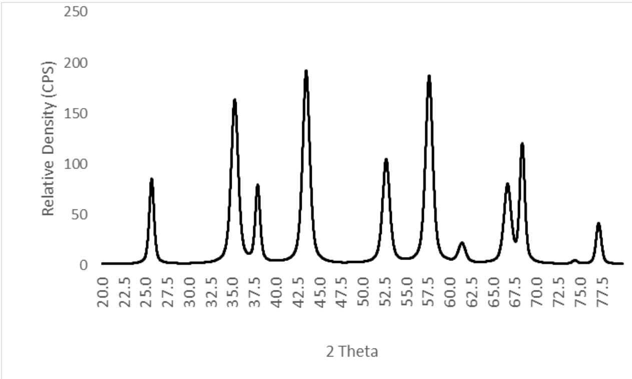


Fig 2. XRD image of Al_2O_3 Nano Particles

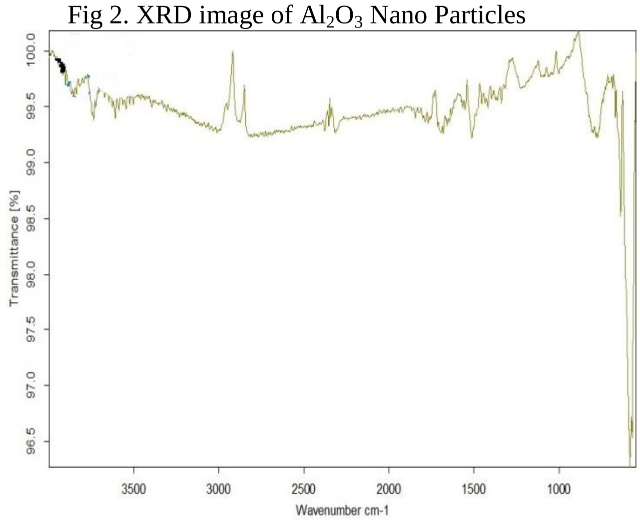
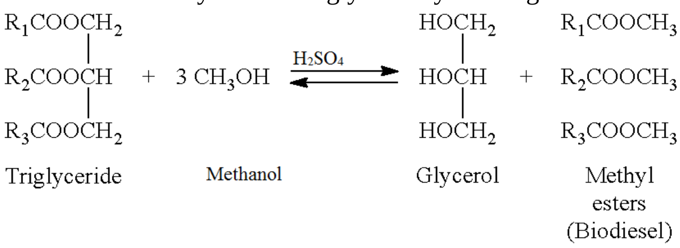


Fig 3. FTIR Analysis of Al_2O_3 Nano Particles

IV. PROCESSING OF BIOFUELS

When jatropha seeds are crushed, the resulting jatropha oil can be processed to produce a high-quality biofuel or biodiesel that can be used as fuel by blending it with standard diesel in diesel engine; The primary purpose of transesterification is to convert the triglycerides from extracted feedstock into methyl ester and glycerol by reacting it with alcohol in the presence of catalyst.



The alkali transesterification method is preferred in this study because of high free fatty acid content of jatropha and pongamia oil which causes easy fatty acid salts (soap) formation. Initially, Crude jatropha oil is poured into a conical flask and heated to a temperature of 60^oC. A mixture of concentrated sulphuric acid H_2SO_4 (1% w/w) with methanol (30% v/v) was heated separately at 50^0C and then it is slowly added to the heated jatropha oil in the flask. The mixture was stirred for about 1 hour and allowed to settle for about 2 hours as shown in fig 4. The products formed during transesterification were Jatropha oil methyl ester and glycerin. The upper layer consists of clean amber colored Jatropha oil methyl ester and the bottom layer consists of glycerin, excess alcohol, catalyst impurities and traces of unreacted oil which will be separated using separating funnel as shown in fig 4. Then the distilled water wash is done about three or four times with a time interval of one hour between each wash. The clear water settled at the bottom of the separation funnel and bio-diesel is formed at top layer.

Similar procedure is followed for processing pongamia biodiesel through transesterification process. The parameters which are influencing the biodiesel yield is found to be reaction time, temperature of operation, quantity of acid and methanol.

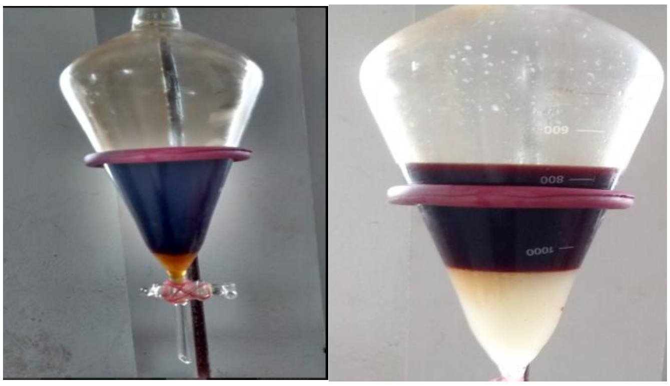


Fig 4 Transesterification process

Ultrasonication

The equipment used for mixing Biodiesel-diesel fuel with Aluminium oxide nanoparticles is an ultra-sonic shaker. The catalytic nanoparticle added with diesel is agitated for about 30 minutes with a fixed frequency rate in an Ultrasonicator to obtain a stable Nano fluid as shown in fig 5. In order to obtain better stability characteristics appropriate volume of surfactants are added with a reaction. The alumina Nano particles are blended with jatropha in the mass fractions of 50,100,150 ppm and with Pongamia biodiesel in the mass fractions of 40, 60 ppm. The Alumina Nano particles were stable in the biodiesel blend for more than 2 days under idle conditions.

Fig 5 Ultrasonication process

V. RESULTS AND DISCUSSIONS

Performance Characteristics

The variations of Brake power with respect to varying load conditions have shown in fig 6. For achieving efficient operation, the engine has to consume less fuel and generate adequate power. From fig 6 it is inferred that there is a slight decrease in Brake power for the addition of both biodiesel and Nano additives under all load conditions. The variations of BSFC and BTHE is shown in fig 7 & 8 respectively. BTHE decreases with an increase in fuel consumption for both JB 20 and PB 20 blends due to its less heating value and higher viscosity of biodiesel. But as the Nano particles are blended with B20 the BSFC seem to reduce with slight increase in BTHE as the surface to volume ratio of added Nano particles are enhanced. At minimum load the Mechanical efficiency of JB20+150 ppm blend is maximum but decreases once the load is increased which is due to increase in indicated power at higher loads and the mechanical efficiency of PB20+60 ppm blend seem to be high at all load conditions.

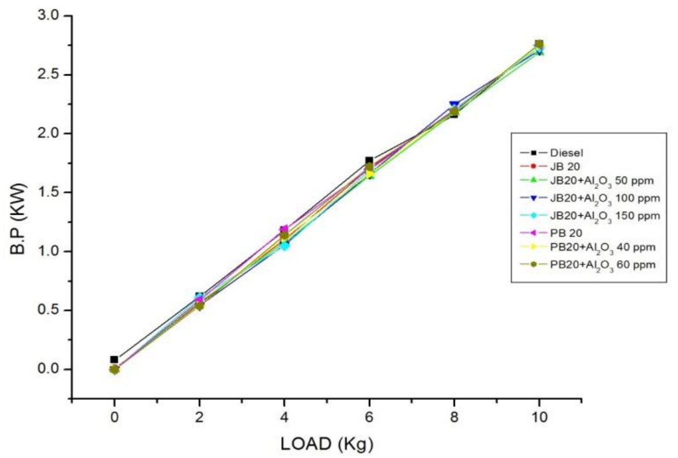


Fig 6 Variation of Brake power for tested fuels

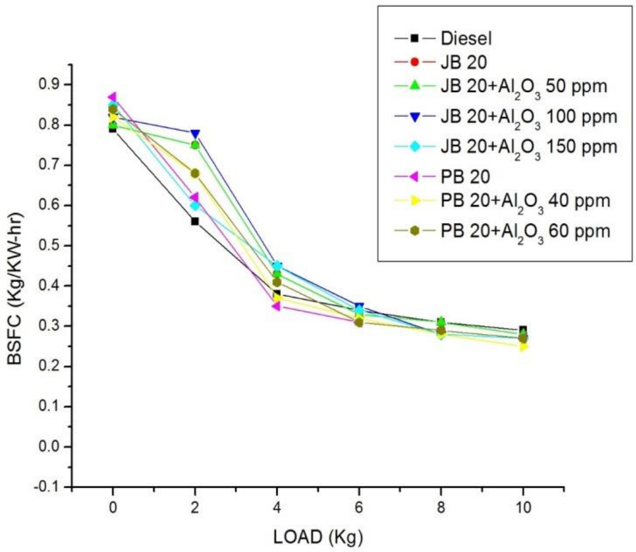


Fig 7 Variation of BSFC for tested fuels

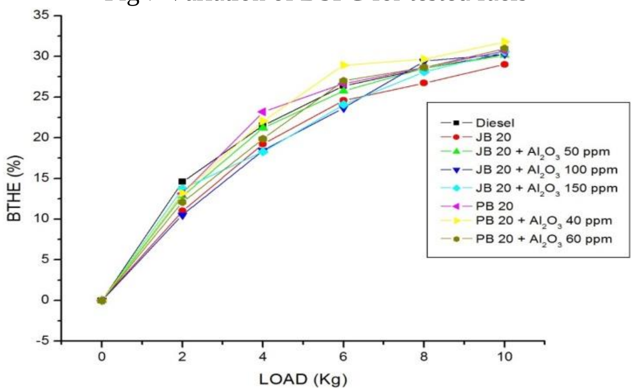


Fig 8 Variation of BTHE for tested fuels

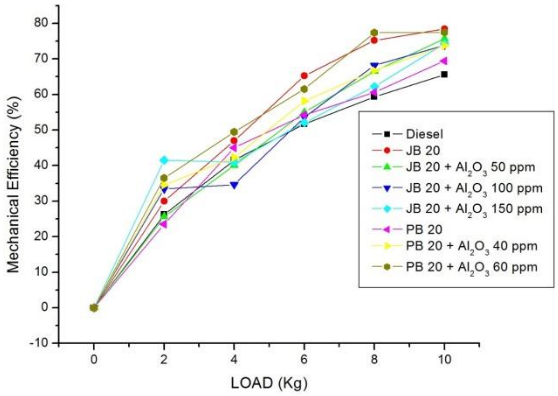


Fig 9 Variation of Mechanical Efficiency for tested fuels

Emission Characteristics

The Primary pollutants in CI engines are CO, Unburned HC, NOx and smoke. The various regions inside the combustion chamber in which CI engine emission constituents are shown in fig 10. The CO and HC is mainly formed in the outer flame region where the fuel mixture is lean due to which incomplete combustion or partial reaction of oxygen molecule occurs. NOx is generally formed by the reaction of Nitrogen present in the air with oxygen at high flame temperature. The formation of NOx is directly proportional to Combustion Flame temperature inside the cylinder. The oxygen content in the biodiesel is higher than diesel. Hence more oxygen will react with Nitrogen resulting in Higher NOx concentration. The figure shows the various regions inside the combustion chamber where emission constituents are formed

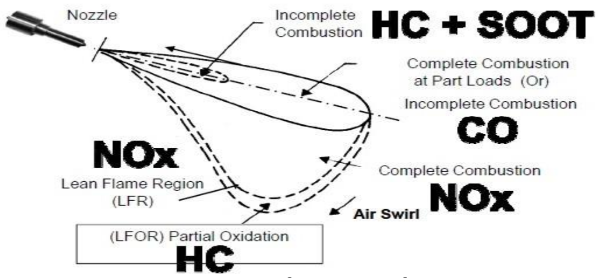


Fig 10 Regions of emission formation

With an addition of JB 20 & PB 20 the CO, HC emissions seem to decrease or remains same with respect to diesel fuel. But as Nano additives are added with it CO emissions are reduced with slight increase in HC emissions as shown in fig 11 &12. With an addition of JB 20 & PB 20 NOx emissions seem to increase and by the addition of Nano additives NOx decreases at lower loads but increases at higher loads as indicated in fig 13.

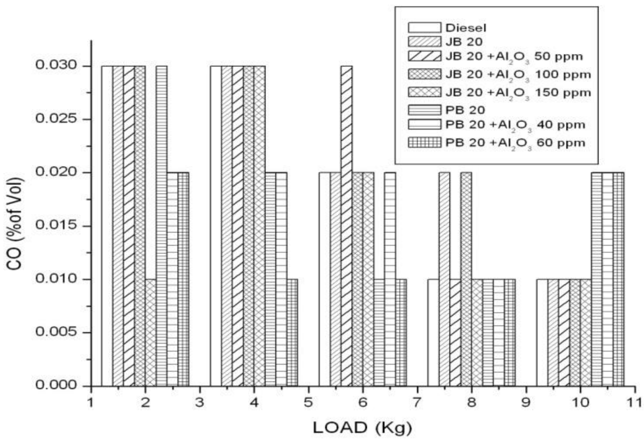


Fig 11 Variation of CO emissions for tested fuels

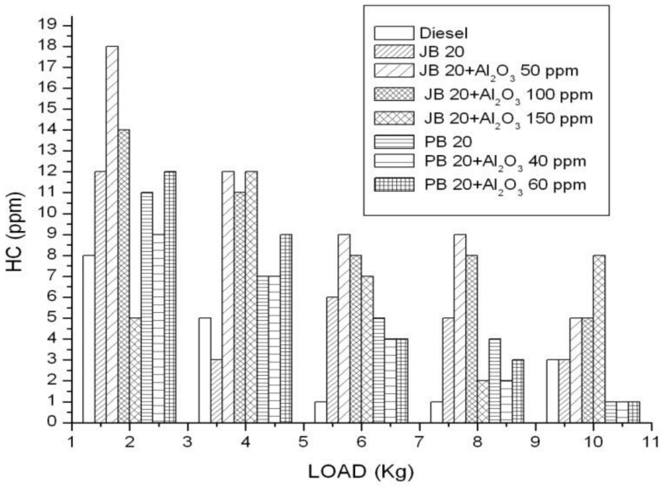


Fig 12 Variation of HC emissions for tested fuels

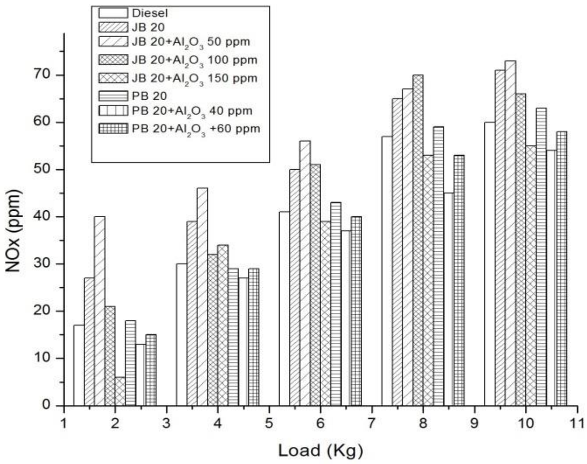


Fig 13 Variation of NOx emissions for tested fuels

VI CONCLUSION

The following conclusions can be extracted by the experimental studies carried out on diesel engine using jatropha, pongamia biodiesels and Alumina Nano particles as fuel:

1. The stability of Nano fluid in the biodiesel was maintained for more than 2 days under standard atmospheric conditions.
2. For the Blend of JB 20 and PB 20 the Brake Thermal Efficiency slightly reduces and consumption of fuel is higher under all load conditions which is due to less heating value and higher viscosity of biodiesel.
3. When the Nano particles are blended with B20 the BSFC seem to reduce with slight increase in BTHE as the surface to volume ratio of added Nano particles are enhanced.
4. With an addition of JB 20 & PB 20 the CO, HC emissions seem to decrease and NOx emission seem to increase in comparison with diesel at all load conditions.
5. When Nano additives are added with Biodiesel CO emissions are reduced with slight increase in HC emissions and NOx decreases at lower loads but increases at higher loads.

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