Effects of Alumina Nanoparticles, Surfactant and Exhaust Gas Recirculation (EGR) on the Performance and Emission Analysis of a Diesel Engine using dual Biodiesel and Diesel Blended Fuel

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Abstract:

An experiment is carried out to evaluate the performance and emission characteristics using dual Biodiesel and diesel blended fuel prepared by adding Aluminum oxide (Al_2O_3) nanoparticles, Surfactant (Triton X100) and using Exhaust Gas Recirculation (EGR) method. These nanoparticles are added to the fuel along with a Surfactant by sonication method and used as a fuel in a diesel engine and results are compared with pure diesel. Results shows that the addition of the nanoparticles and Surfactant increase thermal efficiency by 2% with a slight decrease in fuel consumption and reducing emissions appreciably. Effects of Exhaust Gas Recirculation(EGR) on the performance and emission characteristics of a diesel engine also gives positive results in terms of some of the emissions and dual Biodiesel diesel blended fuel can be claimed to be a potential alternative to diesel in diesel engines.

Keywords— ***Dual biodiesel, Uitrasonication , Nanoparticles, Surfactant, Exhaust gas recirculation (EGR)***

I. INTRODUCTION

In recent years, several experimental studies have focused on dual fuel blends containing one or more bio-fuels forming a combination of bio-fuels with high and low viscosities so that the combined viscosity remains comparable with that of diesel. Experiments with various combinations of biodiesel-methanol, biodiesel-ethanol, cashew nut shell oil-camphor oil, biodiesel-eucalyptus oil etc. are in progress. In this context, (Mohsin *et al.*, 2014) studied the effects of the biodiesel-CNG blend on engine performance and exhaust emission of diesel engine, dual fuel, results indicated better exhaust emission as well as improvement in fuel economy as compared to the base fuel. (Devan *et al.* ,2009) used the combination of eucalyptus oil and methyl ester derived from paradise oil replacing conventional diesel completely; they reported improvements in emission levels and performance was found compared with pure diesel. (Anand *et al.*, 2010) experimented with 10% methanol and 90% Karanj methyl ester in place of diesel and observed improvement in emission characteristics, especially NO_X and smoke, combustion, and performance of diesel engines. (Vallinayagam *et al*. 2014) investigated a dual bio-fuel (pine oil and kapok methyl-ester) strategy to eliminate diesel completely and reported that these fuels could be used directly in diesel engines without any modifications and their emissions HC, CO and smoke reduced by 8.1%, 18.9% and 12.5% respectively at full load and NO_X emission remained similar to the standard diesel.

One of the major conclusions of the numerous investigations concentrating on the strategy of using bio-fuel having a lower viscosity with either diesel or biodiesel in larger proportions essentially depends on the calorific value of the less viscous fuel component (Vallinayagam,2014), Ozeseen (2011). Thus, the alcoholic bio-fuels such as methanol and ethanol can only be used in smaller proportion because of their lower heating values and high latent heat of vaporization (Arpa *et al*, 2010), Bhaskar *et al* (2015) . Further, eucalyptus oil and pine oil also has lower viscosity but simultaneously their heating values are comparable to that of diesel; therefore, they can be used in higher proportions as compared to the alcohols (Vallinayagam *et al*,2014), Anand *et al* (2011) . Table III shows the viscosity and heating values of some of the potential bio-fuels having the low viscosity which can be used with diesel or biodiesel. It is clear from the data enlisted in Table III that properties of Jatropha biodiesel such as the heating value being almost comparable with that of diesel and low cost makes it a better candidate to be used with biodiesel. Although there has already been the some work has been done on Rubber seed biodiesel (Satyanarayana *et al*., 2011), blending of Jatropha biodiesel with Rubber seed biodiesel has not been studied till now. In the present work, experiments on the blend of Jatropha biodiesel and Rubber seed biodiesel having in 50:50 by volume proportions will be designed with a view to eliminate diesel completely yet the improvements in engine performance and emission characteristics can be contemplated. In this study, the combustion, performance and emission characteristics will be comprehensively analyzed and compared for a single cylinder four stroke diesel engine without any modification.

II. MATERIALS AND METHODS

A. Fuel formulation

Stable and homogeneous mixture of dualBiodiesel in base diesel with alumina nanoparticle and surfactant blended fuel containing two bio-fuels forming a combination of both bio-fuels with less cost is formulated so that the combined cost remains smaller compared to that of diesel. Surfactant Triton X100 is used for studying its effect on the performance and emissions of a Diesel engine. Experiments with various combinations of biodiesel-methanol, biodiesel-ethanol, cashew nut shell oil-camphor oil, biodiesel-eucalyptus oil etc. are in progress.

TABLE I: PROPERTIES OF LESS COST FUEL & BIO-FUELS

S. No.	Bio-fuel	Cost(Rs.)	Reference
1	Diesel	70	[10]
2	Jatropha	35	[3]
3	Rubberseed biodiesel	38	[1]
4	Coconutoil biodiesel	65	[26]
5	Palm oil biodiesel	64	[27]

B. Nomenclature of fuel composition

Specification of fuels and their composition used for the experimental study are shown in Table II.

TABLE II: SPECIFICATION OF FUEL COMPOSITION

S. No.	Fuel	Blend
1	100%Diesel+40 PPM Al_2O_3	D100Al40
2	80% Diesel + 10%JBD+10%RSBD	B20
3	80%Diesel+10%JBD+10%RSBD+40 PPM Al_2O_3 + 2% Triton X100+10% EGR	B20Al40S2 E10
4	80%Diesel+10%JBD+10%RSBD+40 PPM Al_2O_3+ 2% Triton X100+15% EGR	B20Al40S2 E15
5	80%Diesel+10%JBD+10%RSBD+40 PPM Al_2O_3+2% Triton X100+20% EGR	B20Al40S2 E20

C. Evaluation of Properties of fuel

The biodiesel fuels, methyl ester composition estimated their thermophysical properties. The properties of biodiesel fuels evaluated based on the assumption that biodiesel is pseudo-components of Kay's rule [34].

Where Xi = methyl ester component molar fraction, Mi = property of methyl ester and M= the property of biodiesel

Properties of turpentine oil and Jatropha methyl ester and dual fuel blends (Jatropha biodiesel and Turpentine oil) are given in Table III.

TABLE III : PROPERTIES OF FUELS USED

S. No.	Items	D100 (Pure Diesel)	B20	B20Al40
1.	Calorific Value (kJ/Kg)	42500	40236	40436
2.	Viscosity @ 40 ^{0}C(mm^2/s)	3.21	4.01	4.09
3.	Cetane index	47.14	45.63	45.84
4.	Density (Kg/m^3)	0.831	0.900	0.862
5.	Flash point, ^{0}C	76	148	135

D. Specification of Engine

The experiments are carried out on a single cylinder, direct injection, Kirloskar , TV1, water cooled, naturally aspirated engine . AVL 437C exhaust gas analyser attached to the computer was used for the measurements of various exhaust gas parameters like CO, HC, Opacity and NO_X .Technical specifications of the engine are given in Table IV.

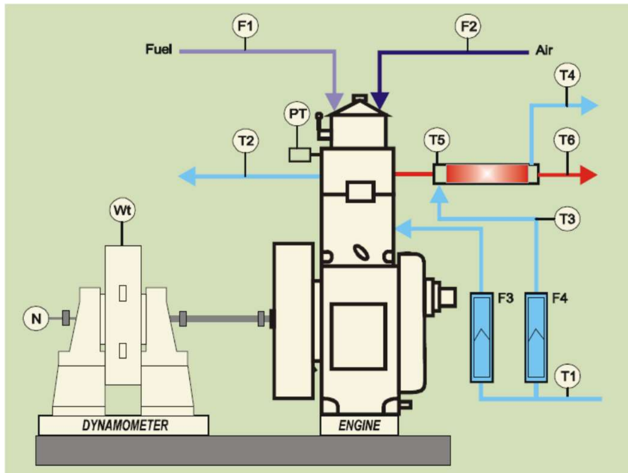

Fig. 1.Engine Test setup

TABLE IV : SPECIFICATION OF ENGINE SETUP

Model	TV1, Kirloskar oil Engine Ltd. India
Type	Single Cylinder, Four stroke, water cooled, constant speed, direct injection, compression ignition engine
Bore	87.5 mm
Stroke	110 mm
Max power	5.2 kW
Speed	1500 rpm
Compressio	17.5:1
Injection	210-220 bar
Governor	Mechanical (centrifugal) type
Dynamome	Eddy current
Pressure	Kistler
Crank angle	magnetic TDC pick up sensor
TDC at	360 crank Angle
Start of	23 deg before TDC
Sensor	Piezo electric
Time	4 µsecond
Resolution	1deg crank angle
Fuel flow	Burette with digital stopwatch

III. Results & Discussion

The combustion phenomenon of the internal compression engine depends on various parameters such as fuel injection pressure, heat release rate, combustion duration, mixing of fuel with air, the inlet temperature of the air, ignition delay and fuel properties like viscosity, calorific value, flash point, density, volatility etc.

In the present investigation, experiments are carried out to estimate combustion, performance and emission parameters of a diesel engine by using dualBiodiesel (Jatropha biodiesel & Rubberseed biodiesel) and mineral diesel blends with Al_2O_3 laden fuel. Blends of Jatropha methyl ester and Rubberseed biodiesel known as dualBiodiesel and diesel laden with Al_2O_3 nanoparticle fuel blends were used and experimental observations were collected to compare the performance and emission properties of blended fuel. The engine was loaded in the range of 25%, 50%, 75%, and full load for the constant speed of 1500 rpm.

A. Brake Thermal Efficiency

Brake thermal efficiency (BTE) of the engine is the fraction of fuel energy converted to useful power output. It is used for evaluating the performance of an engine. Fig. 2 illustrates the variation of brake thermal efficiency with load. The dualBiodiesel fuel blends have higher BTE at no load to full load conditions than standard diesel fuel. It is also observed that BTE improved is due to the reduction in friction losses and increases in brake power with the increase in load. The lower volatility and higher viscosity of Jatropha biodiesel resulted in the poor fragmentation and combustion characteristics, but oxygen molecules present in the dualBiodiesel fuel blends slightly improves the combustion characteristics. Therefore, BTE was found to be higher for all dualBiodiesel fuel blend compared to conventional D100(Pure diesel). (Chauhan *et al.* 2012) reported low BTE, when tested with the blend of diesel and Jatropha methyl ester. (Kumar *et al*. 2003) investigated the Jatropha methyl ester and methanol blends on the diesel engine and reported low BTE. (Paula *et al.,*2014) investigated the diesel and Jatropha methyl ester oil on a diesel engine and reported the lower BTE than diesel fuel. (Anand *et al*. 2010) examined the conventional diesel and turpentine fuel on the diesel engine and reported low BTE than the conventional diesel fuel. It was observed that the magnitude of BTE for pure diesel, B20, B20Al40S2E10, B20Al40S2E15, B20Al40S2E20 and D100Al40 was found to be 34.29,33.78, 33.74 ,34.12 and 33.14 for full load condition respectively. It can be shown from the figure that the thermal efficiency (BTE) for dual Biodiesel and all its diesel blends laden with nano particles is higher compared to the pure diesel.

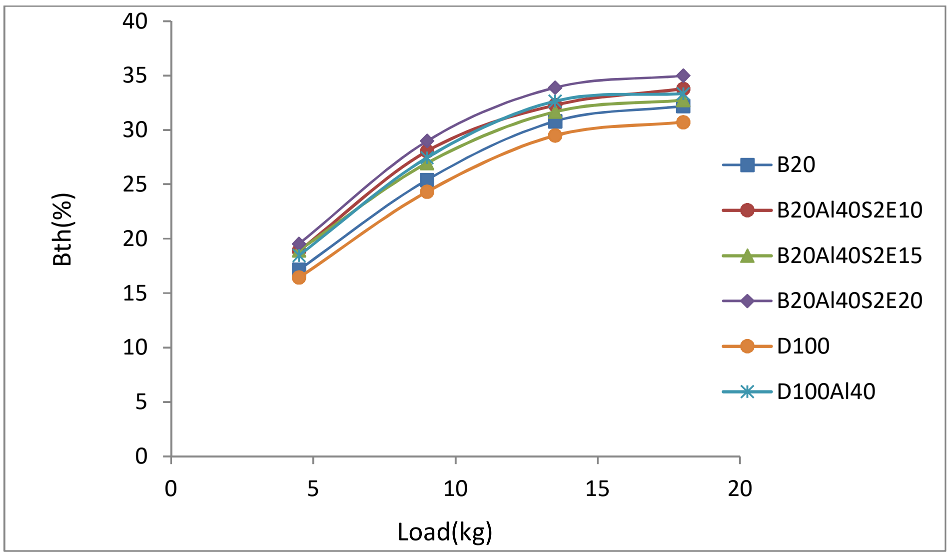

Fig. 2. Variation of B_{th} at different engine loads

B. Specific Fuel Consumption

Fig.3 shows the Variation of BSFC at different engine loads for dual Biodiesel and its diesel blends laden with nano particles.The Specific Fuel Consumption for standard diesel, B20, B20Al40S2E10, B20Al40S2E15, B20Al40S2E20, and D100Al40 fuel blends were measured to be 0.26, 0.26, 0.26, 0.25, and 0.26 respectively at full load. It may be due to the cetane rating of the fuel; standard diesel fuel has a higher cetane rating than dual Biodiesel and dual Biodiesel and diesel blends laden with nano particles. In addition to this, the temperature of combustion chamber also plays an important role in fuel ignition. However it can be shown from the figure that fuel consumption for dual Biodiesel and its diesel blends laden with nano particles is comparable to the D100.

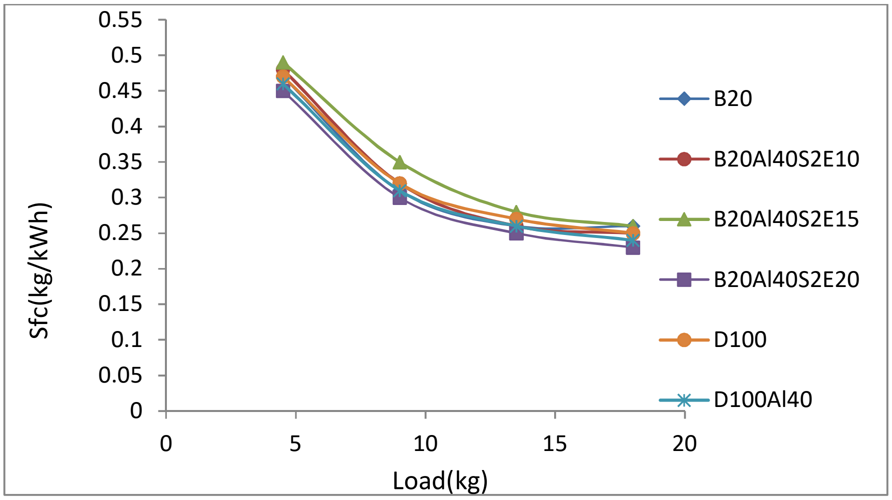

Fig. 3. Variation of BSFC at different engine loads

C. NO_X Emission

Fig. 4 shows the comparison of NO_X emissions of dual Biodiesel and its diesel blends laden with nano particles. NO_X emission in idle condition is same for standard diesel as well as the B20, dual Biodiesel (Jatropha Biodiesel – Rubber seed Biodiesel) and diesel blend, while NO_X emission for B20 is lower as compared to standard diesel at all loads which closely follows the results of tested biodiesels reported by many authors. This is due to the shorter combustion duration and higher ignition delay. This possibly allows more time for cooling inside the combustion chamber. Incidentally, (Vallinayagam *et al*. 2014) have also reported lower NO_X while testing pine oil and kapok methyl ester oil. He reported that some blends shows higher NO_X emissions than conventional diesel fuel. This is due to the lower percentage of turpentine oil and the higher percentage of Jatropha biodiesel and its density. It was also observed by (Ozsezen *et al*. 2011) that an increase in fuel density results in higher NO_X emissions. The dual fuel blends recommended that the optimum NO_X level for 75% load condition and that may be favorable in a trade-off between NO_X and BSFC with little brake efficiency reduction which exhibits that Rubber seed Biodiesel fuel having moderate percentage of (up to 50%) is observed to provide a delicate balance between the NO_X emission and fuel economy and the brake power. As the Rubber seed Biodiesel percentage increases in the dual Biodiesel and diesel fuel blend the NO_X emission decreases and BSFC also decreases. This also substantiated by (Karthikeyan *et al.* 2007) who suggested that 50% turpentine oil closely follow the trends of diesel fuel, however, for turpentine oil percentage greater than 50% renders the combustion abnormal. After the point of trade-off, the NO_X emission decreases and the BSFC increases till the full load. B20 reveals the optimum results for both the condition for lower NO_X and lower BSFC than all the dual Biodiesel and diesel blends laden with nanoparticles and pure diesel. However, D100Al40S2E20 has much lower NOx emissions compared to dual Biodiesel and its diesel blends laden with nano particles(B20) and D100 as well as D100Al40.

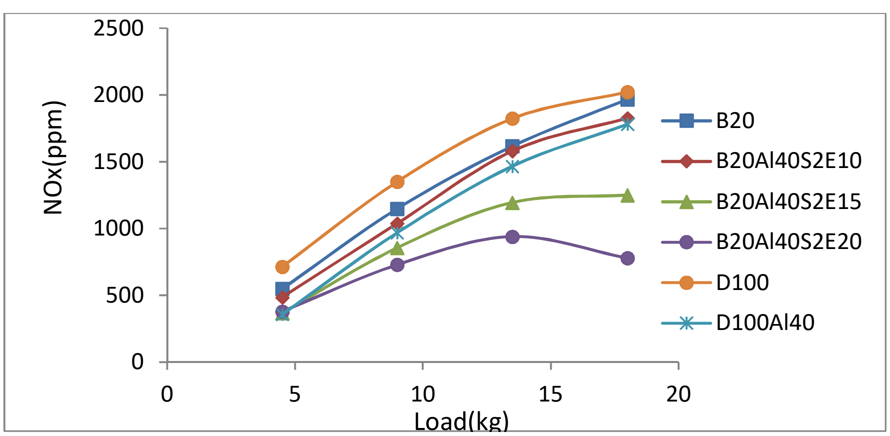

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Fig.4. NO_x emissions at different engine loads

D. CO Emission

The CO emission of the dual fuel blend and pure diesel fuel are shown in Fig. 5 for various load conditions (no load, 2 5 %, 50%, 75% and full load). Carbon monoxide is generally formed when there is insufficient oxygen to burn the fuel. Diesel engines generally work in excess air; therefore, diesel engines produce lower CO emissions than petrol engines (Sharon *et al*.,2012). It can be observed from Fig. 5 that CO emission in g/kWh decreases with increasing brake power. Dual Biodiesel and its blends with nanoparticles were found to produce much lower CO emission as compared to conventional diesel fuel at full load due to the availability of excess O_2 and complete combustion of the dual fuel blends. The CO emission for diesel, B20, B20Al40S2E10, B20Al40S2E15, B20Al40S2E20 and D100Al40 full load condition has observed to be 0.155.225, 0.285 , 0.289 and 0.110 respectively. This results were supported by (Sharma *et al.* 2013) who reported lower CO emissions when tested Jatropha biodiesel and tyre pyrolysis oil in single cylinder diesel engine compared to D100(pure diesel).

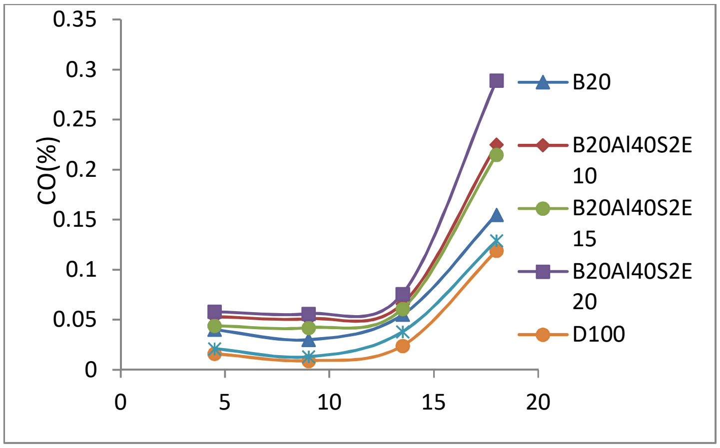

Fig. 5. CO emissions at different engine loads

E . HC Emission

Unburned hydrocarbons (HC) emissions are the hydrocarbons emitted after combustion of petroleum fuel in an engine. Fig. 6 presents HC emissions of standard diesel and dual Biodiesel and its blends tested on a single cylinder, constant speed (1500 RPM) diesel engine. Dual Biodiesel and its blends with nanoparticles exhibit lower HC emissions at all load conditions than pure diesel fuel. This may be because of the density of the dual Biodiesel and its blends with nanoparticles that affects the spray entrenchment. Moreover, at low loads, the cooling effect of the charge played a significant role due to lower combustion temperatures. However, at higher loads, the difference between HC emissions emanating from dual Biodiesel is more compared to its blends with nanoparticles and that from the standard diesel fuel is smaller due to complete combustion. D100Al40 and B20 shows lower HC emissions at all load condition than all dual Biodiesel and diesel blends with 40 ppm nanoparticles 2% Surfactant and using all three EGR levels tested. This results were supported by (Bhupendra *et al*., 2012) who investigated the Jatropha biodiesel and its blends with diesel fuel on the diesel engine and resulted in lower HC emissions.

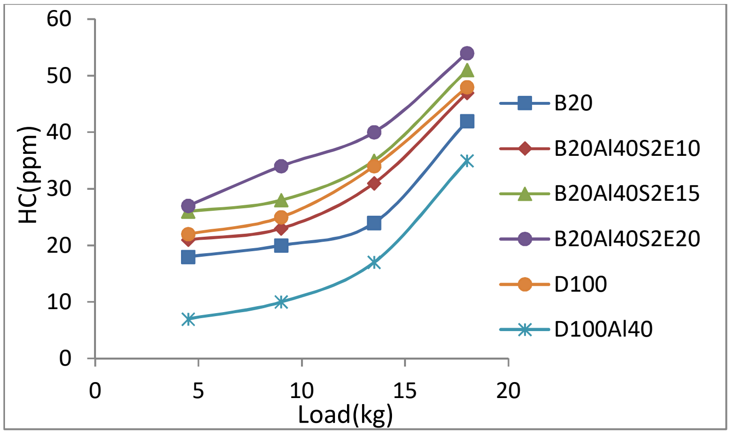

Fig. 6. HC emissions at different engine loads

F. Smoke Emission

Fig. 7 shows the smoke emission measurement for standard diesel and dual fuel blend. Smoke emission is found lower for dual fuel blends as compared to conventional diesel fuel at all loads for which test was carried out. It can be deduced from Fig. 7 that smoke emission decreases with the increase of load for dual Biodiesel,and most of its blends with nanoparticles and D100(pure diesel). Further, it can also be inferred that smoke emission emanating from dual fuel blend is higher in case of Jatropha biodiesel but it is lower in case of conventional diesel. The dual Biodiesel exhibit lower smoke at part load than its blends with nanoparticles and pure diesel. It is due to oxygen content in the Jatropha biodiesel and higher cetane rating. This results were supported by (Bhupendra *et al.,* 2012) who examined the Jatropha biodiesel and its blends with conventional diesel on the diesel engine and resulted in lower smoke emissions.

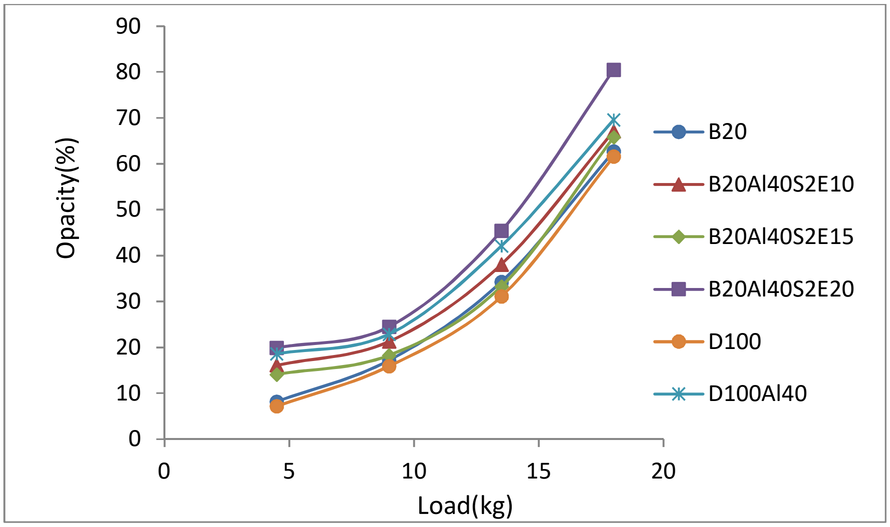

Fig 7. Smoke opacity emissions at different engine loads

IV. CONCLUSIONS

In this work a dual Biodiesel and diesel blend, Jatropha biodiesel and rubber seed biodiesel combination is used in a diesel engine on cost basis, to eliminate the use of standard diesel to some extent and without any modification to diesel engine. In this work, the properties of both biofuels are acceptable and favourable to use in the diesel engine. The dual Biodiesel and diesel blends were investigated and combustion, performance and emission characteristics of the engine are compared with B20, D100Al40S2 and Pure diesel . The important points are as follows.

1. By the use of Exhaust Gas Recirculation(EGR), Alumina nano particle laden dual Biodiesel and diesel blends (B20Al40S2E10, B20Al40S2E15 and B20Al40S2E20),Diesel engine run successfully & smoothly and performed better; the BTE for B20Al40S2E20 blend has nearer value to B20 ,D100Al40 blends and 100(pure diesel).
2. Irrespective of the load conditions dual Biodiesel blends with diesel laden with nano additives, B20Al40S2E20 blend gives almost similar results in case of CO_2, CO, HC and smoke emission as compared to B20Al40S2E10 and B20Al40S2E15 blends . Moreover, at full load condition, NO_X emission decreases by nearly 60% when compared to both B20, B20Al40S2 blends and D100 (pure diesel) .
3. At all load conditions D100Al40 gives lower NOx than all blends and lower CO & HC emissions compared to all blends and B20 and D100(pure diesel).
4. Rubber seed methyl ester has higher volatility and higher viscosity compared to Jatropha methyl ester, which might have caused proper mixing and complete combustion for Jatropha methyl ester and micro explosion caused by nano additives ;also nano fluid stability achieved through Surfactant and inherent oxygen in the biodiesel structure plays a significant role in compensating oxygen deficient operation, therefore, Alumina nanoparticle laden dual Biodiesel and diesel blend with nano additives ,Surfactant and hot EGR (B20Al40S2E20) gives higher performance and closer emissions to B20, B20Al40S2 blends and D100(pure diesel).

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NOMENCLATURE

BSFC: Brake specific fuel consumption

RSBD: Rubber Seed Bio Diesel

JBD : Jatropha Bio Diesel

PPM: Parts Per Million

Bth : Brake thermal efficiency

Nox :Nitric oxides

CO :Carbon monoxide

HC :Hydro carbon