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Effect of phenol group antioxidant on performance and emission characteristics of variable compression ratio diesel engine fuelled with diesel-palm biodiesel blend

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Abstract— In conventional CI engine diesel is used as a fuel which provides better power, efficiency and basic specific fuel consumption, but it increases the CO_2, CO, HC, SOX and NOx emission. These gases affect the environment and human health. It causes global warming, greenhouse effect and responsible for acid rain too. Diesel is nonrenewable energy resources and increases our dependency for importing fuel on other country. Due to depleting the fossil fuel and increasing effect of environment pollution from this fuel demands an ecofriendly alternative which can be used in diesel engine without any design modification. In this present work, palm-biodiesel and diesel blend B20 (20%palm biodiesel and 80% diesel) was used as alternate fuel. It was observed that compression ignition engine with B20 emits higher level of NOx emission compared to pure diesel as fuel. Higher level of NOx emission can be reduced by adding phenol group antioxidant in biodiesel and its blend. Experiment has been done by taking palm biodiesel blend B20 at variable compression ratio for 4 stroke diesel engine. Result for performance and emission characteristics were analyzed.

Keywords— Phenol group antioxidant, Palm biodiesel-diesel blends, NOx reduction, variable compression ratio, CI engine

Nomenclature

CI	Compressed ignition	B20	20% Palm biodiesel and 80% Diesel
VCR	Variable compression ratio	BHA	Butylated hydroxyanisole
CR	Compression ratio	BHT	Butylated hydroxytoluene
POME	Palm oil methyl ester	TBHQ	tert-Butylhydroquinone
CO2	Carbon dioxide	ppm	Parts per million
CO	Carbon monoxide	BP	Brake power
HC	Unburned hydrocarbon	BTE	Brake thermal efficiency
NOx	Oxides of nitrogen	BSFC	Brake specific fuel consumption

I. INTRODUCTION

From previous studies, Straight vegetable oils used in engine lead to various problems like fuel filter clocking, poor atomization and incomplete combustion because it is highly viscous, high density and poor non volatility. In order to reduce the viscosity of the straight vegetable oil the following four techniques are adopted; namely (1)heating/pyrolysis, (2)dilution/blending, (3)micro-emulsion and (4)transesterification. Among these the transesterification is an extensive, convenient and most promising method for reduction of viscosity and density of the straight vegetable oils. However, this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs.

II. Biodiesel production

The Palm oil was collected from local market. For preparation of palm biodiesel from palm oil transesterification process was used. The palm oil was preheated into flask with temperature (between 60-80°C) until the palm oil contents were in a semi-transparent, dark brown, viscosed liquid form. After that preheated palm oil was mixed homogonously and stored in container. The alkali catalyst Naoh and methanol solution was prepared to produce sodium methoxide and stir this mixture for 10 minute for proper mixing. After that the mixture of Naoh and methanol is added into preheated palm oil and stir this mixture vigorously for 40 to 50 minutes to start the transesterification reaction. After the specific duration of the reaction completed, the reaction's product was allowed to settle over night (24 h). The reaction's result was two distinct liquid phases; the first was the Palm Oil Methyl Ester (POME) or the biodiesel on the top and the second was the denser phase of glycerol. Methyl ester was separated by separating funnel. Then mixture of Palm Biodiesel is washed by hot water three times. Glycerol is highly soluble in water and biodiesel is not soluble in water which makes a different layer of water mixing glycerol which is separated by funnel and biodiesel is obtained.

TABLE 1
PROPERTIES OF PALM BIODIESEL

Parameters	Units	Value
Density @ 15 C	kg/m^3	899
Kinematic viscosity@40 C	Centi poise	16.43
Kinematic viscosity@110 C	Centi poise	10.65
Iodine value	-----	118
Acid value	mg KOH/gm	28
Flash point	℃	139
Fire point	℃	153
Gross calorific value	kJ/kg	42690

III. Blend preparation

B20 blend is prepared by mixing palm biodiesel and diesel fuel in a bottle by volume/volume percentage. In B20, 20% of palm biodiesel is added in 80% of diesel fuel. (E.g. in 1 litre of fuel 200 ml palm biodiesel and 800 ml diesel). For addition of antioxidant different antioxidant is added to blend in different proportion by measuring its weight by electronic weight measurement instrument for regarding ppm calculating from its density and molecular weight. For preparation of B20+200ppm BHA, B20+500ppm BHA and B20+1000ppm BHA, proportion of 200 mg, 500 mg and 1000 mg BHA is directly added into B20 respectively. It shows 200ppm, 500ppm and 1000ppm of antioxidant in fuel blend.

IV. Experimental setup

Fig. 1 Experimental setup

1. Single cylinder four stroke diesel engine
2. Eddy current dynamometer
3. Rotameter
4. Air box
5. Fuel tank
6. Burette
7. Fuel control valve
8. Load cell
9. Pressure sensor
10. Performance testing machine
11. AVL exhaust gas analyser
12. Exhaust probe

TABLE 2 ENGINE SPECIFICATION

Parameter	Specifications
Make	Kirloskar
Model	AV1
Method of cooling	Water cooled
Rated power	5 HP
Engine speed	1500 RPM
Bore × Stroke	87 mm × 110 mm
Volume	553 c.c
Compression Ratio	Variable from 16.5 to 8.73

V. EXPERIMENTAL APPROACH

Effect of 1000ppm of three different phenol group antioxidant (BHA,BHT and TBHQ) on NOx emission comparing with Diesel-Biodiesel blend B20 is evaluated by comparison of emission characteristic of fuels at two different compression ratio 16.5 and 13.89, in constant speed variable compression ratio diesel engine. First, the best suitable phenol group antioxidant for maximum NOx emission reduction compared to B20, among BHA, BHT and TBHQ can be find out, for both the compression ratio. After that different quantity of the selected antioxidant 200ppm, 500ppm and 1000ppm can be added in B20. Later the experimental investigation is done at two different compression ratio 16.5 and 13.89, on all the fuels and comparison of their performance and emission characteristics can be done. After comparing the performance and emission characteristics, the best proportion of selected antioxidant in blend B20 for both compression ratio can be find out.

VI. RESULT AND DISCUSSION

5.1COMPARISON OF ANTIOXIDANTS WITH NOX EMISSION

The experiments were done with Diesel fuel, B20 and B20 with 1000 ppm of BHA, BHT and TBHQ at two compression ratio 16.5 and 13.89. NOx emissions for all the tested fuels are recorded. Following graphs shows the variation of NOx emission with increase in % Load for all the fuels.

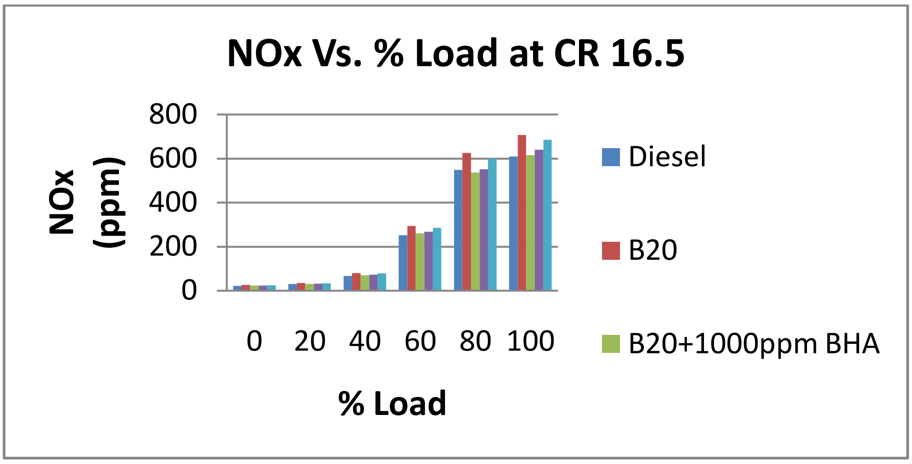

Fig.1 Comparision of antioxidants with NOx emission Vs. % Load at CR 16.5

At compression ratio 16.5 it has been observed that NOx emission increase with increase in load for all the fuels. Diesel gives minimum NOx emission compared to other fuels at all the load conditions. Blend B20 gives maximum NOx emission compared to other fuels. Addition of 1000ppm of antioxidants BHA, BHT and TBHQ decrease the NOx emission compared to B20 blend. Average NOx reduction for B20 + 1000ppm BHA, B20 + 1000ppm BHT and B20 + 1000ppm TBHQ compared to B20 at compression ratio 16.5 is 12.35%, 9.81% and 3.23%. Maximum NOx emission reduction 16.5% compared to B20 was observed in B20 with 1000ppm BHA.

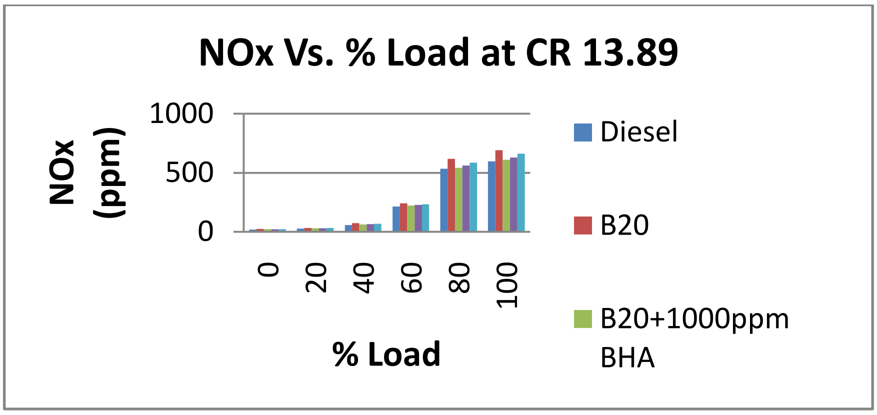

Fig. 2 Comparison of antioxidants with NOx emission Vs. % Load at CR 13.89

At compression ratio 16.5 it has been observed that NOx emission increase with increase in load for all the fuels. Diesel gives minimum NOx emission compared to other fuels at all the load conditions. Blend B20 gives maximum NOx emission compared to other fuels. Addition of 1000ppm of antioxidants BHA, BHT and TBHQ decrease the NOx emission compared to B20 blend. Average NOx reduction for B20 + 1000ppm BHA, B20 + 1000ppm BHT and B20 + 1000ppm TBHQ compared to B20 at compression ratio 16.5 is 12.35%, 9.81% and 3.23%. Maximum NOx emission reduction 16.5% compared to B20 was observed in B20 with 1000ppm BHA.

At lower compression ratio 13.89 NOx emissions for all the tested fuels were lower compared to higher compression ratio 16.5 for all the load conditions. Maximum NOx reduction was found in fuel B20 with 1000ppm BHA. Average NOx reduction for B20 + 1000ppm BHA, B20 + 1000ppm BHT and B20 + 1000ppm TBHQ compared to B20 at compression ratio 13.89 is 9.53%, 7.61% and 3.49% respectively.

It can be concluded that the efficiency of antioxidants for NOx reduction compared to B20, investigated in the present study was as follows: BHA>BHT>TBHQ. Therefore antioxidant BHA was selected for experimental investigation of performance and emission characteristics of diesel-palm biodiesel blend B20 at two different compression ratios 16.5 and 13.89.

5.2 Engine Performance Data

Engine performance parameter like Brake power, brake specific fuel consumption and brake thermal efficiency respectively are discussed with diesel fuel, B20 and B20 with 200ppm, 500ppm and 1000ppm of BHA at different load conditions.

5.2.1 Brake Power

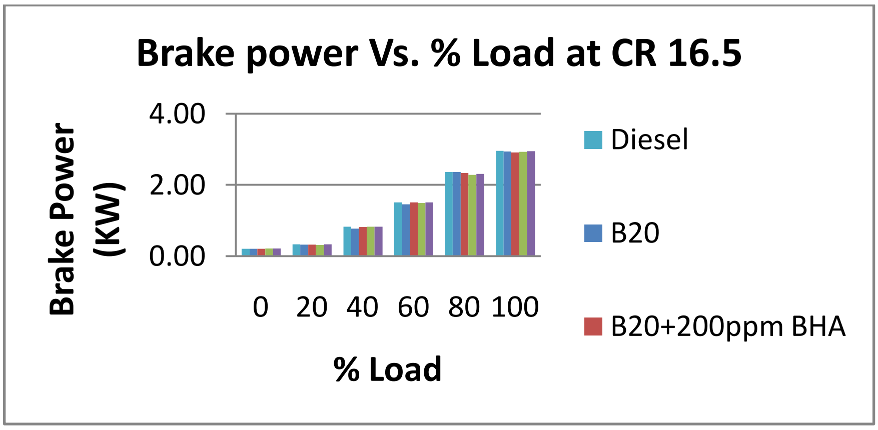

Fig. 3 Brake power Vs. % Load at CR 16.5

Brake power with different load condition at compression ratio 16.5 for all the tested fuels diesel, B20, B20 + 200ppm BHA, B20 + 500ppm BHA, B20 + 1000ppm BHA are shown in above graph. It has been observed that Brake power increase with increase in engine load for all tested fuels. Brake powers for other fuels were slightly lower compared to diesel at all loads. Addition of antioxidants increase Brake power at lower load and decrease Brake power at higher load compared to B20. B20 decrease 2.56% average Brake power compared to Diesel. Addition of 200, 500 and 1000ppm of BHA increase average Brake power 1.51%, 1.68% and 3.08% respectively compared to B20.

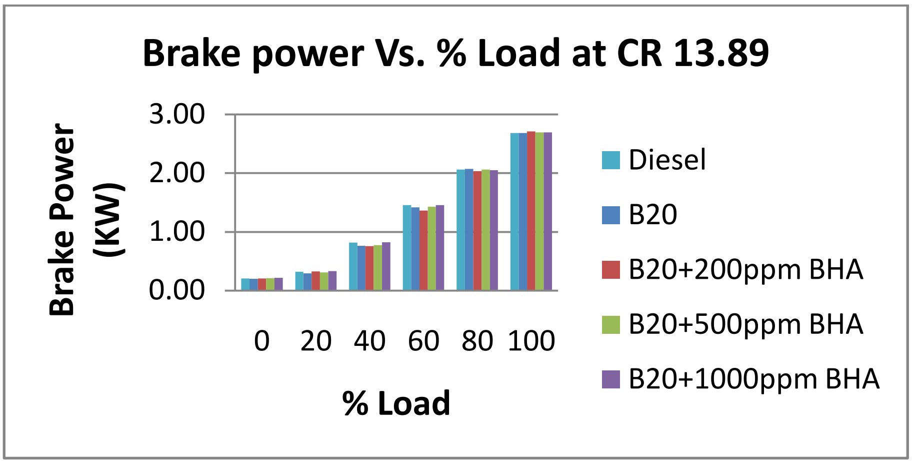

Fig. 4 Brake power Vs. % Load at CR 13.89

At lower compression ratio 13.89 same trend as higher compression ratio was observed for Brake power vs. Load graph for all the tested fuels. B20 decreases 3.06% average Brake power compared to Diesel. Addition of 200, 500 and 1000ppm of BHA increase average Brake power 0.98%, 2.08% and 5.02% compared to B20 for all the loads.

Diesel-Palm biodiesel blend B20 produces lower Brake power than diesel because Palm biodiesel have higher kinematic viscosity and higher density, resulting in less combustion despite the higher oxygen content in molecular structure. The higher power output of B20+BHA could be attributed to a number of causes. The higher density and kinematic viscosity of the added-antioxidant fuels result in the injection of a larger mass of fuel to the engine for the same fuel volume. And from literature it has been observed that addition of antioxidants increases cetane number. Thus, higher CN and higher mass flow might have helped to achieve a better power output with added-antioxidant blends compared to B20.

5.2.3 Brake Specific Fuel Consumption

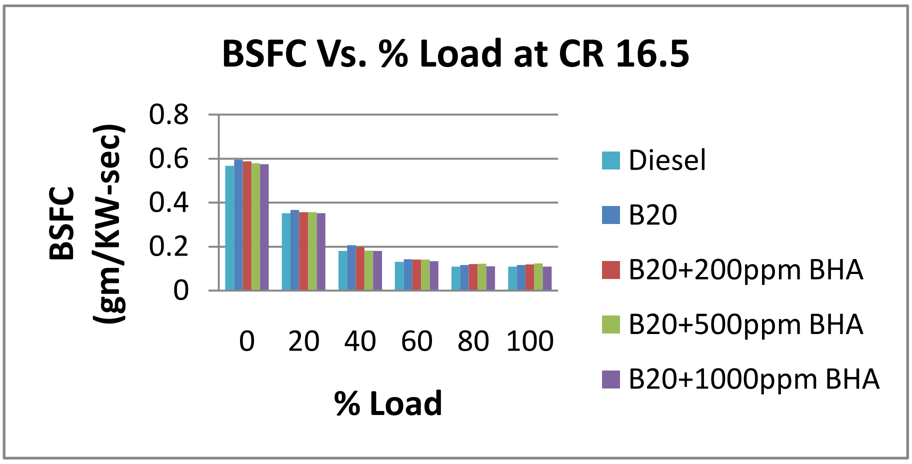

Fig. 5 BSFC Vs. % Load at CR 16.5

Brake specific fuel consumption for all the tested fuels at compression ratio 16.5 with various load conditions are shown as graph below. It has been observed that BSFC was decreased with increase in load for all the tested fuels. BSFC for B20 increased compared to Diesel at all the loads. Decrease in BSFC was observed for B20 after addition of antioxidant from load 0% to 60%. At higher loads 80% and 100% addition of 200ppm and 500ppm BHA increase BSFC but addition of 1000ppm of BHA decrease BSFC compared to B20. Average increase in BSFC for B20 compared to Diesel was 7.53%. Addition of 200,500 and 1000ppm BHA decreases average BSFC 0.44%, 1.22% and 6.15% compared to B20. Addition of 1000ppm of BHA gives better BSFC compared to B20.

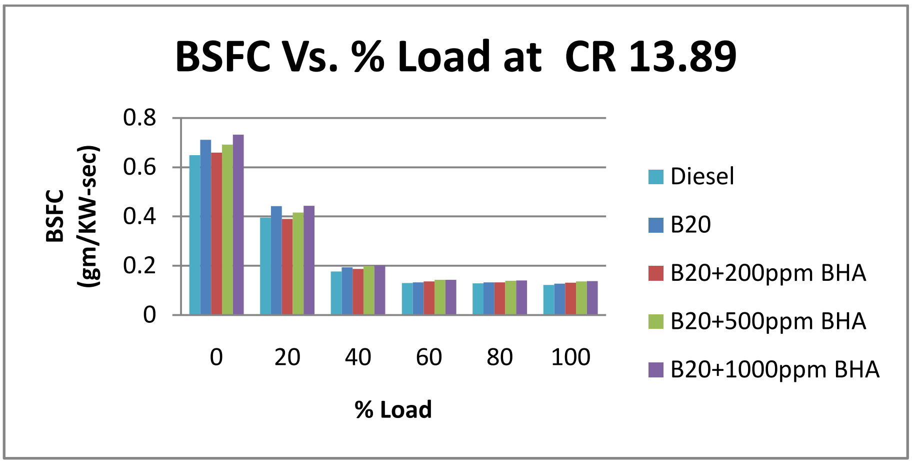

Fig. 6 BSFC Vs. % Load at CR 13.89

At lower compression ratio 13.89 different trend was observed compared to higher compression ratio for BSFC. BSFC for B20 is increased compared to diesel for all loads at lower compression ratio. From load 0% to 60% addition of 200ppm BHA gives better BSFC compared to B20. For 80% load BSFC for B20 and B20 + 200ppm BHA remains same and for 100% load BSFC for B20 + 200ppm slightly increased compared to B20. B20 + 500ppm BHA gives lower BSFC compared to B20 for 0% and 20% load and for other loads BSFC increases. BSFC for B20 + 1000ppm BHA increase for all the loads compared to B20. B20 increase average 6.60% BSFC compared to diesel. Addition of 200ppm BHA decreases average 2.60% BSFC compared to B20. B20 + 500ppm BHA and B20 + 1000ppm BHA increase average BSFC 2.43% and 4.78% compared to B20 respectively.

Brake specific fuel consumption for all the tested fuels is decreasing as load increasing and BSFC for higher compression ratio is lower compared with the lower compression ratio. This is due to at higher compression ratio and higher load the energy required per kilo watt is lesser than that of lower compression ratio. The reason for higher BSFC for B20 compared to Diesel is, due to higher density, higher viscosity and lower calorific value of the B20. The addition of antioxidants to B20 reduces its calorific value and BSFC. It was due to higher power output.

5.2.3 Brake Thermal Efficiency

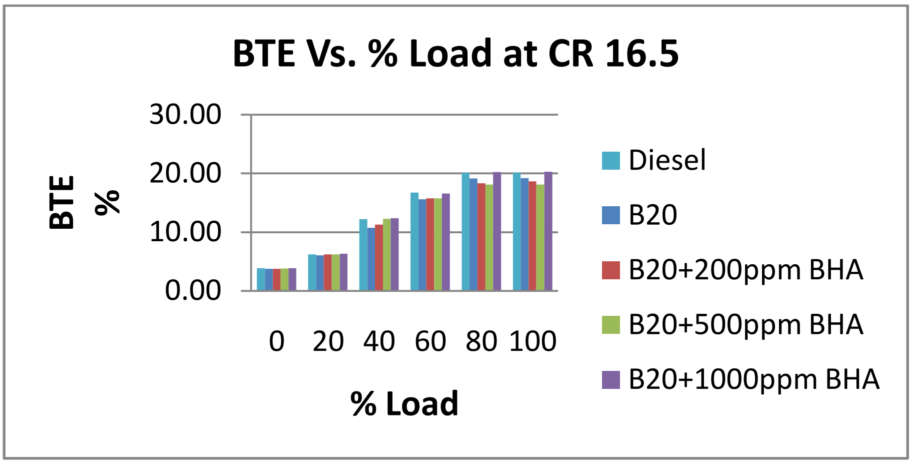

Fig. 7 BTE Vs. % Load at CR 16.5

The brake thermal efficiency for all the tested fuels at compression ratio 16.5 at different load condition are as shown in chart above. Brake thermal efficiency is lower than diesel for B20 at all the loads. As antioxidant proportion in B20 increases from 200ppm to 1000ppm Brake thermal efficiency is increases for 0% load to 60% load. For 80% and 100% load BTE is lower than B20 for B20 + 200ppm BHA and B20 + 500ppm BHA. For all the loads B20 + 1000ppm BHA gives maximum BTE compared to all the tested fuels at all the loads. Average decrease in Brake thermal efficiency for B20 is 5.73% compared to Diesel. Addition of 200,500 and 1000ppm BHA in B20 increase 0.54%, 1.65% and 6.73% BTE respectively, compared to B20.

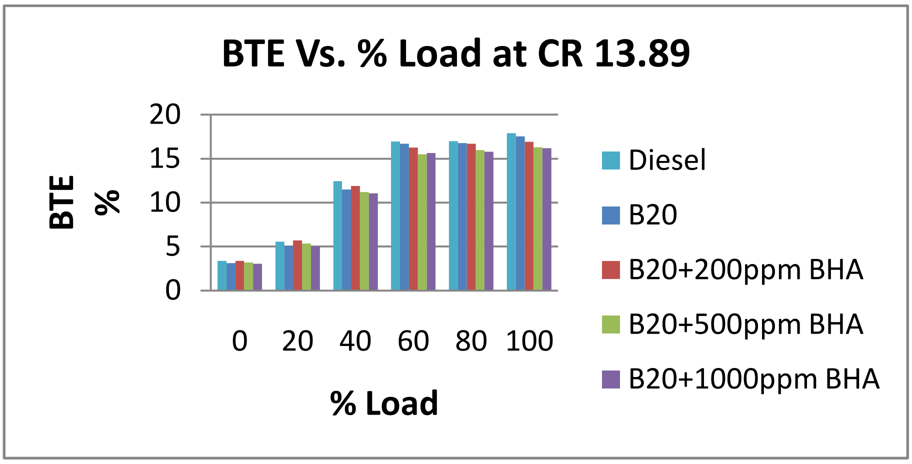

Fig. 8 BTE Vs. % Load at CR 13.89

Brake thermal efficiency at lower compression ratio 13.89 for all the tested fuels are as shown as above graph for different loads. BTE for B20 is lower than diesel at all the loads. For 0% to 40% loads B20 + 200ppm BHA gives better BTE and for other loads BTE remains lower compared to B20. Other fuels B20 + 500ppm BHA and B20 + 1000ppm BHA gives lower BTE than B20 at all the loads. B20 decreases average 4.90% BTE compared to Diesel. Addition of 200ppm BHA increase average BTE 2.95% and addition of 500 and 1000ppm BHA decreases average 2.14% and 4.50% BTE compared to B20.

From the experiment it was observed that BTE increases with increasing in load for all the tested fuels. It was due to increase in power developed with increase in load. By increasing the compression ratio of the engine, the brake thermal efficiency also increased for all the fuel types tested. Brake thermal efficiency is directly proportionate to the compression ratio and load. The lower BTE of B20 is due to the combined effect of their lower heating value and higher viscosity. The addition of antioxidant BHA into B20 increased the BTE, which is due to the higher power output and lower BSFC compared to B20.

5.3 ENGINE EMISSION CHARACTERISTICS

Variation of emission parameter like unburnt hydro carbon (HC), carbon monoxide (CO) and nitrogen oxide (NO) at two different compression ratios 16.5 and 13.89 with different load conditions are recorded and discussed as below.

5.3.1 Hydro Carbon (HC)

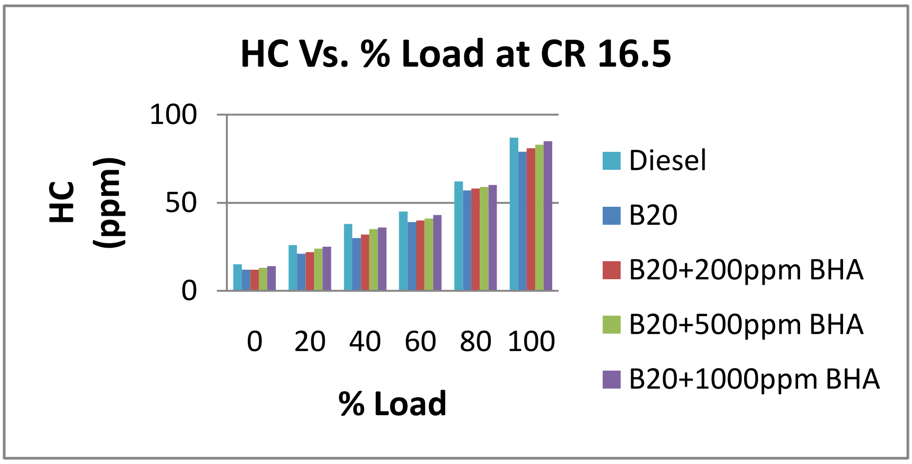

Fig. 9 HC emission Vs. % Load at CR 16.5

As shown in above graph hydrocarbon emission at compression ratio 16.5 for all the tested fuels is increasing as load increase. Compared to diesel B20 gives less HC emission at all the loads. As proportion of antioxidants in B20 increase the HC emission is also increase. Maximum HC emission was observed in B20 + 1000ppm BHA compared to B20, B20 + 200ppm BHA and B20 + 500ppm BHA. Average decrease in HC emission for B20 compared to Diesel is 15.15%. Addition of 200,500 and 1000ppm of BHA in B20 increase average 3.05%, 8.83% and 13.14% HC emission compared to B20 respectively. But compared to diesel it remains lower.

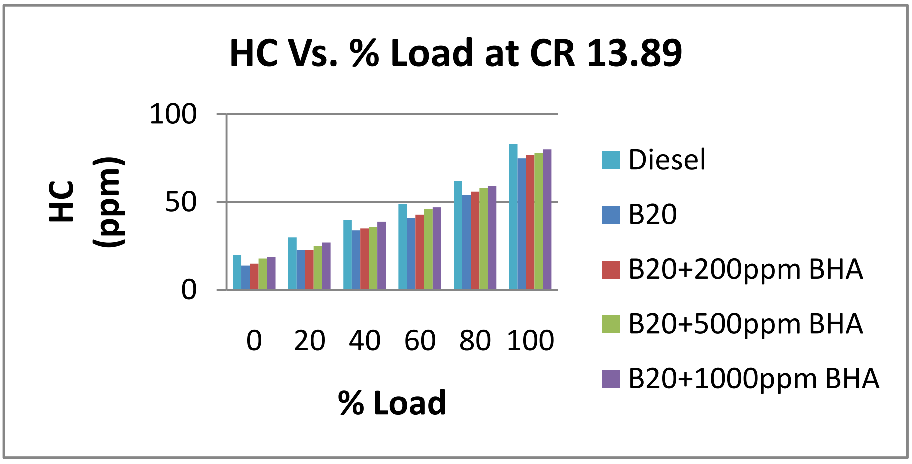

Fig. 10 HC emission Vs. % Load at CR 13.89

At lower compression ratio 13.89 same trends for HC emission was observed as higher compression ratio 16.5. Addition of antioxidant increase the HC emission compared to B20 but it remains lower compared to diesel for all the loads. As proportion of BHA increase HC emission increase and B20 + 1000ppm BHA gives maximum HC emission compared to B20, B20 + 200ppm BHA and B20 + 500ppm BHA. B20 decrease average HC emission 17.87% compared to Diesel. Addition of 200,500 and 1000ppm BHA increases average HC emission by 3.55%, 8.74% and 14.01% respectively compared to B20.

It was observed that at higher compression ratio HC emission is lower compared to lower compression ratio for all the tested fuels. This may be due to increased temperature and pressure at higher compression ratio and better combustion can be ensured. Diesel-Palm biodiesel blend B20 produce lesser HC emission compared to Diesel. This is due to the inbuilt oxygen content in its molecular structure this may be responsible for complete combustion and thus reducing the unburnt HC levels. Addition of BHA into B20 increases HC emission. This increase is due to the reduction in oxidative free-radical formation.

5.3.2 Carbon Monoxide (CO)

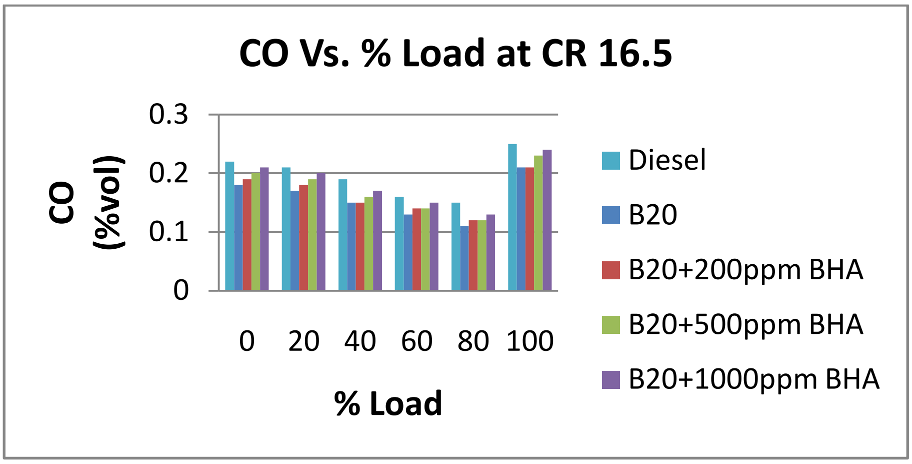

Fig. 11 CO emission Vs. % Load at CR 16.5

As shown in figure CO emission is lower for B20 compared to diesel at all the loads at compression ratio 16.5. Addition of BHA increase CO emission compared to B20 but it remains lower compared to diesel. Maximum CO emission is found in B20 + 1000ppm BHA compared to B20, B20 + 200ppm BHA and B20 + 500ppm BHA. Average decrease in CO emission for B20 compared to Diesel is 19.95%. Addition of 200,500 and 1000ppm of BHA increases average CO emission by 4.70%, 9.30% and 15.91% respectively compared to B20.

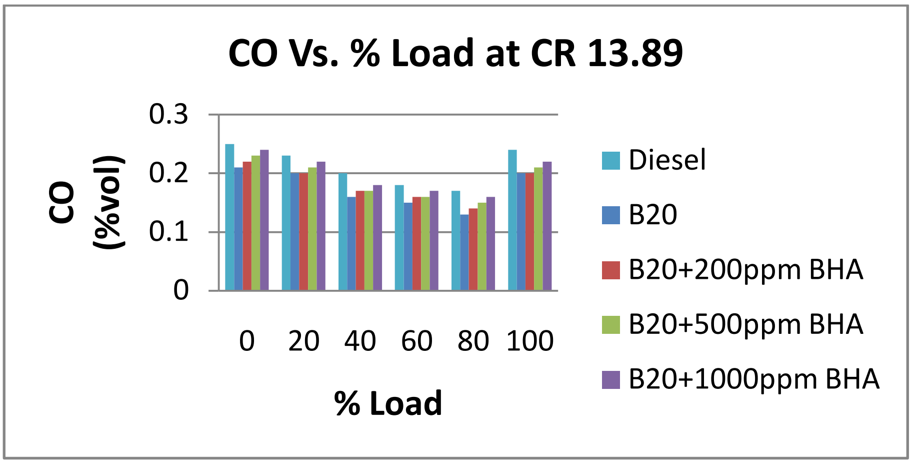

Fig. 12 CO emission Vs. % Load at CR 13.89

As shown in figure same trend was observed for lower compression ratio 13.89 for all the tested fuels as higher compression ratio 16.5. B20 decrease CO emission compared to Diesel. Average reduction in CO emission is 17.65% for B20 compared to Diesel. Adding BHA into B20 increases CO emission compared to B20, but it remains lower compared to Diesel. Addition of 200,500 and 1000ppm of BHA increases average CO emission by 4.23%, 7.97% and 13.86%.

At lower Compression ratio, insufficient heat of compression delays ignition and so CO emissions increase. The possible reason for this trend could be that the higher Compression ratio actually increases the air temperature inside the cylinder therefore reducing the ignition lag which causes better and more complete burning of the fuel. It has been observed that B20 emits lower CO compared to Diesel. In the blend B20 the more amount of oxygen in the bio diesel accounts for better combustion inside the cylinder and hence reduced CO emission. Addition of the antioxidant BHA produced mean increases in CO emission. This increase in the CO emissions after adding antioxidant was due to the incomplete combustion related to amount of OH radicals (oxidation inhibitor) in the combustion reaction. Antioxidant reduces oxidation between carbon and oxygen molecules due to presence of OH radicals in its chemical structure.

5.3.3 NITROGEN OXIDES (NOX)

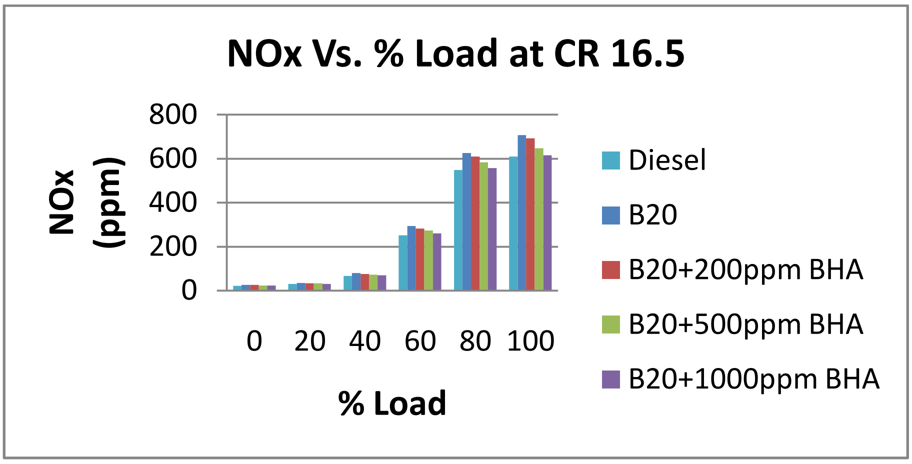

Fig. 13 NOx emission Vs. % Load at CR 16.5

NOx emission for different loads at compression ratio 16.5 is shown in figure above. B20 emits higher NOx compared to diesel at all the loads. To decrease higher emission of NOx BHA is added into B20. As proportion of BHA is increase in B20 the value of NOx emission decreases and B20 + 1000ppm BHA gives minimum NOx emission compared to B20, B20 + 200ppm BHA and B20 + 500ppm BHA. Average increase in NOx emission for B20 compared to Diesel is 16.78%. Addition of 200,500 and 1000ppm BHA in B20 decreases average NOx emission by 2.93%, 7.34% and 11.82% respectively compared to B20.

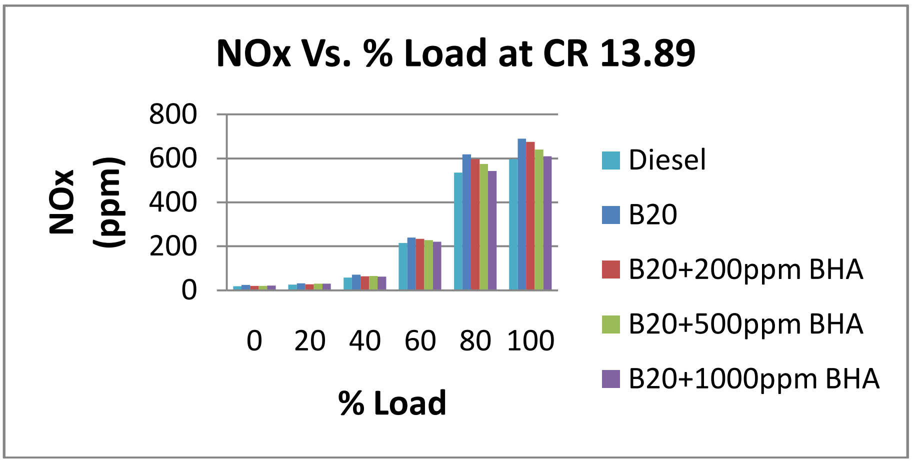

Fig. 14 NOx emission Vs. % Load at CR 13.89

As shown in figure above at lower compression ratio 13.89 NOx emission is decreased as compared to higher compression ratio for all the fuels at all the loads. Same trend like higher compression ratio 16.5 for NOx vs. Load graph is observed at lower compression ratio 13.89 for all the fuels. Addition of 1000ppm of BHA gives maximum NOx reduction compared to B20. Average reduction in NOx emission for B20 is 19.37% compared to Diesel. Addition of 200,500 and 1000ppm of BHA in B20 decrease average NOx reduction by 8.06%, 7.95% and 9.53% respectively compared to B20.

It has been observed that the NOx emission for higher compression ratio is higher compared to lower compression ratio. This is due to better mixing of air and fuel at higher compression ratio which improves the combustion thereby combustion temperature increases. NOx emission for B20 is higher compared to Diesel. During biodiesel combustion in diesel engine, the production rate of free radicals is higher. The reaction between molecular nitrogen and hydrocarbon radicals (CH, CH2, C2, C and CH2) is crucial in NOx formation. Addition of BHA decrease the amount of NOx emission compared to Diesel. The lower exhaust gas temperature of B20 + BHA supports this phenomenon. It can also be attributed that the phenolic hydroxyl groups present in BHA interfere with the prompt NOx mechanism.

VII. CONCLUSION

The aim of this experimental work was to investigate the effect of phenol group antioxidant on performance and emission characteristics of variable compression ratio diesel engine fuelled with diesel-palm biodiesel blend. The following conclusions can be drawn based on the experimental results:

1. The efficiency of phenol group antioxidants BHA, BHT and TBHQ for NOx emission reduction for both compression ratio investigated in present study was as follows: BHA>BHT>TBHQ.

2. Engine Brake power is higher at higher compression ratio compared to lower compression ratio for all the fuels. B20 decrease BP compared to diesel at both compression ratio. Addition of antioxidants increase BP compared to B20. Maximum increase in BP compared to B20 was found in fuel B20 + 1000ppm BHA at both compression ratio. Addition of 1000ppm BHA increase average BP 3.08% and 5.02% compared to B20 at CR 16.5 and 13.89 respectively.

3. BSFC at higher CR is lower compared to lower CR for all the fuels. B20 increase BSFC at both compression ratio compared to Diesel. Addition of BHA decrease BSFC compared to B20. Maximum decrease in BSFC compared to B20 was found in addition 1000ppm BHA at higher CR and 200ppm at lower CR. Addition of 1000ppm BHA decrease average BSFC by 6.15% compared to B20 at higher CR. Addition of 200ppm BHA decrease average BSFC by 2.60% compared to B20 at lower CR
4. BTE is increasing with increase in CR. Brake thermal efficiency is directly proportionate to the compression ratio and load. B20 decrease BTE compared to diesel at both compression ratio. Maximum increase in BTE compared to B20 was found in addition 1000ppm BHA at higher CR and 200ppm at lower CR. Addition of 1000ppm BHA in B20 increase 6.73% average BTE at higher CR. Addition of 200ppm BHA in B20 increase average BTE by 2.95% at lower CR.
5. CO and HC emission is lower at higher CR compared to lower CR for all the tested fuels. B20 reduce CO and HC emission compared to Diesel at both CR. Average reduction in CO and HC emission for B20 compared to Diesel is 19.95 and 15.15% at higher CR, and 17.65% and 17.87% at lower CR.
6. Addition of all the proportion of BHA into B20 increases CO and HC emission compared to B20. Addition of 1000ppm of BHA in B20, increase CO and HC emission by 15.91% and 13.14% respectively at higher CR. 200ppm of BHA in B20 increase average CO and HC emission by 13.86% and 14.01% respectively, at lower CR compared to B20.
7. NOx emission for higher compression ratio is higher compared to lower compression ratio. Average increase in NOx emission for B20 compared to Diesel is 16.78% and 19.37% respectively at higher CR and lower CR. Maximum reduction in NOx emission compared to B20 was found in addition of 1000ppm BHA at both CR. Addition 1000ppm BHA in B20 decrease average NOx emission 11.82% at higher CR and 9.53% at lower CR, compared to B20.

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