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Experimental Investigation Of Performance And Emission Characteristics Of Ci Engine Using Graphene Nanoparticles As An Additive In Biodiesel

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ABSTRACT

An experimental investigation were carried out to determine performance and emission characteristics of diesel engine using diesel, honge oil methyl ester [HOME] and nanoparticles blended biodiesel fuels. The base line data was generated using neat diesel.
The biodiesel was prepared from Honge Oil by transesrerification process. The graphene nanoparticles were blended with the biodiesel fuel in the mass fraction of 25 ppm and 50 ppm with the aid of a mechanical homogenizer and ultrasonicator. For ensuring proper swirling of air and fuel in combustion chamber for efficient combustion, modifications were made for piston by providing four equidistance tangential grooves(for each piston 5mm, 6mm, 7mm widths and with common depth of 2mm respectively) on the hemispherical piston crown.The results were compared for the different alternatives. Experimental set-up consists of a single-cylinder diesel engine coupled with an eddy current dynamometer for loading, five gas analyser for exhaust gas analysis, Hartridge smoke meter. The engine performance and the emission parameters like carbon monoxide, unburned hydrocarbons and oxides of nitrogen were analysed. During analysis it was observed that the HOME+GRAPHENE 50PPM gives higher brake thermal efficiency than that of HOME+GRAPHENE 25PPM as a fuel. Further HOME+GRAPHENE 50PPM biodiesel and piston modification with slot of 6mm width and 2mm depth was found with proper swirling of air and fuel and efficient combustion.

Keywords— **Graphene nanoparticles, Diesel engine, HOME(Honge Oil Methyl Ester), Biodiesel, graphene nanoparticle-biodiesel blends, Ultrasonicator, and Emission.**

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I. INTRODUCTION

The diesel engines have their special advantages like durability, reliability and fuel economy then gasoline engines. Diesel engines cause higher emission of particulate matter (PM), carbon monoxide (CO), Hydrocarbon and nitric oxides causing various global hazards such as climatic change, ozone layer depletion, green house effect, global warming, smog, acid rain water bodies and reduce in air quality. Due to the increased hazardous effects of emission from engine, to reduce these effects many researchers have contributed their work by different ways like engine modification, fuel alteration ex-haust gas treatment [1]. In this way engines are operated with biodiesels without modification of previous engines. The performance characteristics of engine with biodiesels are little less compared to the base fuel diesel. Many researchers are experimentally investigated by adding additives like metal and metal oxides nanoparticles, liquids (methanol, ethanol) to the biodiesels. Recent understanding and advance in materials science have led to exciting potentials in the development of propulsion fuels. These include Nano particles, nanotubes, graphene and reactive Nano composite powders. In this view the nanoparticles are added to base fuel due to their most remarkable properties like thermal properties, mechanical properties, Specific Surface Area [m^2/g], magnetic, electric properties, optical properties, reactivity, high surface to volume ratios and energy densities [1]. Graphene has attracted much attention from researchers due to its interesting mechanical, electrochemical and electronic properties. Graphene, a single atomic layer of sp^2-bonded carbon atoms tightly packed in a two dimensional (2D) honeycomb lattice, has evoked great interest throughout the scientific community since its discovery [1-4]. As a novel nanomaterial, graphene possesses unique electronic, optical, thermal, and mechanical properties. Yetter et al., [2] have critically reviewed the reports on metal nano particles combustion and revealed that the nano size metallic powders possess high specific surface area and potential to store energy, which leads to high reactivity. A single atomic layer of graphene is the thinnest sp^2 allotrope of carbon. It, therefore, has various unique electrical and optical properties of interest to scientists and technologist [3]. Sabourin et al., [4] have compared the combustion of the monopropellant nitro methane with that of nitro methane containing colloidal particles of functionalized graphene sheets. Catalytic activity of FGS is expected to occur on both sides of the graphene sheets. The fuel colloids studied, particularly ones containing FGSs, enhance the reaction rates through several mechanisms including enhanced heat transfer (radiation and conduction) and chemical reactivity (catalysis and carbon oxidation). The ignition temperatures were lowered and burning rates increased for the colloidal suspensions compared to those of the liquid monopropellant alone, with the graphene sheet suspension having significantly greater burning rates (i.e., greater than 175%). Graphene is an exciting material. It has a large theoretical specific surface area, high intrinsic mobility, high Young's modulus and thermal conductivity and its optical transmittance (97.7%) and good electrical conductivity [5, 6]. Sadhik Basha et.al. [7, 8] have used alumina and carbon nanotubes nanoparticles as additives to the biodiesels. They concluded that the nano-particles can function as a catalyst and an energy carrier, as well. In addition, due to the small scale of nanoparticles, the stability of the fuel suspensions should be markedly improved. Arul et al., [9] investigated diesel engine using cerium oxide nanoparticles. The cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NOx.

II. HOME – GRAPHENE BLENDS PREPARATION

To prepare HOME-graphene blends, graphene nano particles are initially weighted using electronic balance. Nanoparticles are weighed separately for quantities 25mg and 50mg accurately. The nanoparticles blended honge biodiesel fuel is prepared by mixing the honge biodiesel and graphene nanoparticles with the aid of an ultrasonicator (Fig. 1).

The ultrasonicator technique is the best suited method to disperse the graphene nanoparticles in a fluid, as it facilitates possible agglomerate nanoparticles back to nanometre range. The nanoparticles are weighed to a predefined mass fraction say 25ppm and dispersed in the honge biodiesel fuel. This blend prepared is called HOME25GRAPHENE. The same procedure is carried out for the mass fraction of 50ppm to prepare the graphene nanoparticles blended honge biodiesel fuel (HOME50GRAPHENE).

Figure 1: Ultrasonicator

The samples of grapheme nanoparticles blended honge biodiesel fuels are kept in bottles under static conditions for analysing the stability characters. After the preparation of nanoparticle biodiesel blends properties like flash point, kinematic viscosity and calorific value of prepared blend were determined and are tabulated as shown in Table 1. Table 2 shows the properties of nanoparticles used.

Table 1: Properties nanoparticle-biodiesel blends.

Type of fuel	Flash point, °C	Kinematic Viscosity, cSt @ 40 °C	Net calorific value, MJ/kg	Density @15 °C
Diesel	56	3	43	840
HOME	170	5.6	36.016	880
HOME 25 GRAPHENE	160	5.8	35.00	895
HOME 50 GRAPHENE	158	5.8	35.50	900

Table 2: Properties of nanoparticles used for present study

Sl. No	Parameters	Graphene Nanoparticles
1	Manufacturer	Karnataka University Dharwad
2	Bulk/ true density – g/cc	-----
3	Average particle size (APS) – nm	22.5-26
4	Surface area (SSA) m^2/g	492
5	Purity - %	99.7
5	Thermal conductivity –W/mK	3000

III. EXPERIMENTAL SETUP

For the experiments conducted injection timing, injection opening pressure and compression ratio were kept at 23° bTDC, 205 bar and 17.5 for diesel operation and 19° bTDC, 230 bar and 17.5 for HOME –graphene nanoparticle blends. Table 3 below shows the specifications of engine.

Table 3: Specifications of Engine test rig

Sl No	Diesel engine	
	Parameters	**Specification**
1	Type of engine	Kirloskar Single cylinder four stroke direct injection diesel engine
2	Nozzle opening pressure	200 to 205 bar
3	Rated power	5.2 KW (7 HP) @1500 RPM
4	Cylinder diameter (Bore)	87.5 mm
5	Stroke length	110 mm
6	Compression ratio	17.5 : 1

A. Transesterification setup:

Transesterification was carried out in a system which is shown in the figure 2. Three necked flat bottomed glass flask of 2liter capacity was used for transesterification reaction. A double coiled reflux condenser was fitted to a neck of the glass flask for condensing methanol vapors during the reaction. Water was circulated through coils of the condenser. A plate heater with a magnetic stirrer was used for uniform heating of the contents of the flask.

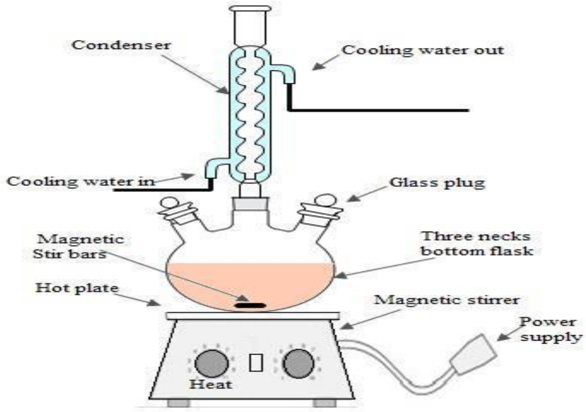
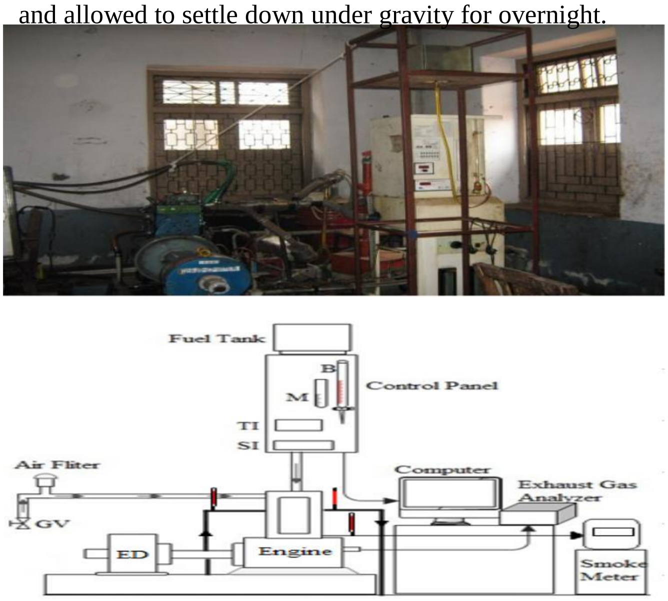


Figure 2: Transesterification setup

Honge oil, methanol and NaOH were transferred through the third neck of the flask.

In the transesterification process triglycerides of Honge oil react with methyl alcohol in the presence of a catalyst (NaOH) to produce fatty acid ester and glycerol. In this process 1000 gm of Honge oil, 200 gm methanol and 8 gm sodium hydroxide were taken in a round bottom flask. Items required for transesterification process are Honge, Methanol, Sodium hydroxide containers. All the contents were heated up to 65^{0}C to70^{0}C and stirred by the magnetic stirrer vigorously for one hour when the ester formation begins. The mixture was transferred to a separating funnel and allowed to settle down under gravity for overnight.



ED- Eddy Current Dynamometer, M-Manometer, TI-Temperature Indicator (^{0}C), SI-Speed Indicator (rpm), B- Burette, GV-Gate valve

Figure 3: Experimental test rig

The upper layer in the separating funnel forms the ester and the lower layer being glycerol was removed from the mixture. The separated ester was mixed with 250 gm of hot water and allowed to settle under gravity for 24 hours. Water washing removes the fatty acids and catalyst dissolved in the lower layer and was separated. Fatty acids and dissolved catalyst were removed by using a separator funnel.

Table 3 Specification of CI Engine

Sl No	Diesel engine	
	Parameters	**Specification**
1	Type of engine	Kirloskar Single cylinder four stroke direct injection diesel engine
2	Nozzle opening pressure	200 to 205 bar
3	Rated power	5.2 KW (7 HP) @1500 RPM
4	Cylinder diameter (Bore)	87.5 mm
5	Stroke length	110 mm
6	Compression ratio	17.5 : 1

IV. RESULTS AND DISCUSION

A. Effect Of Diesel, Home +25ppm And Home+ 50 Ppm Nanoparticles

1) Variation of brake thermal efficiency

Figure 4 shows variation of brake thermal efficiency for Diesel, HOME and HOME+GRAPHENE blended fuels. The HOME results in inferior performance due to its higher viscosity and lower volatility and lower calorific value. However the brake thermal efficiency of the HOME+GRAPHENE blended fuels is improved compared to neat HOME operation. This could probably be attributed to the better combustion characteristics of HOME+GRAPHENE. In general, the Nano size particles possess high surface area and reactive surfaces that contribute to higher chemical reactivity to act as a potential catalyst. In this perspective, the catalytic activity of HOME+GRAPHENE could have improved due to the existence of high surface area and active surfaces. Moreover, in case of HOME+50GRAPHENE fuel, the catalytic activity may enhance due to the high dosage of compared to that of and HOME+25GRAPHENE. Due to this effect, the brake thermal efficiency is higher for HOME+50GRAPHENE compared to that of HOME+25GRAPHENE. The maximum brake thermal efficiency for HOME+50GRAPHENE is 24.8 percent, compared to 22% for HOME and 25.8 for neat diesel, at the 80% load respectively.

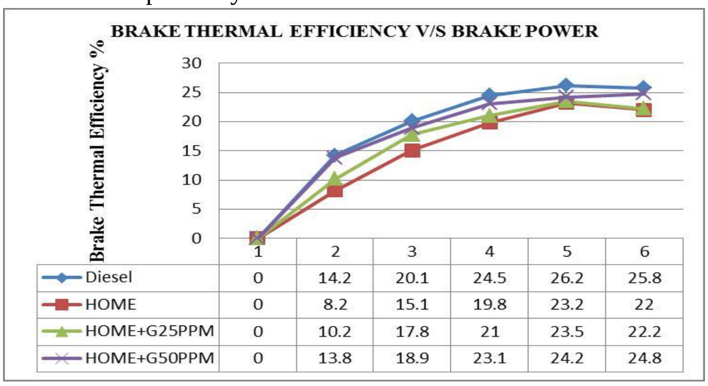
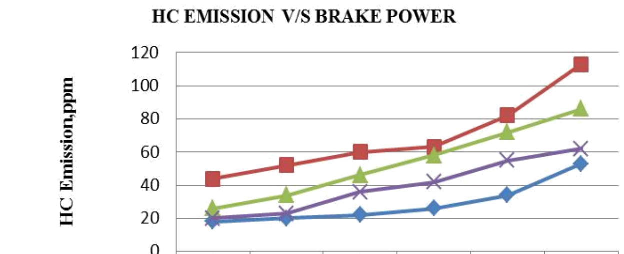


Figure 4: Variation of Brake Thermal Efficiency with Brake power

2) Variation of HC emission

Figure 5 shows variations of unburnt HC emission for HOME and HOME- GRAPHENE nanoparticle blended fuels. The HC emission for HOME operation was higher compared to diesel due to its lower brake thermal efficiency resulting from incomplete combustion. However HC emissions were marginally lower for the HOME-GRAPHENE blended fuels compared to HOME alone operation. This could be due to increased catalytic activity and improved combustion characteristics of GRAPHENE which lead to improved combustion. HOME+50 GRAPHENE showed better performance with comparatively lower HC as compared to HOME+25 GRAPHENE due to the increased dosing level of GRAPHENE nanoparticles that provided higher surface area resulting in improved combustion characteristics.

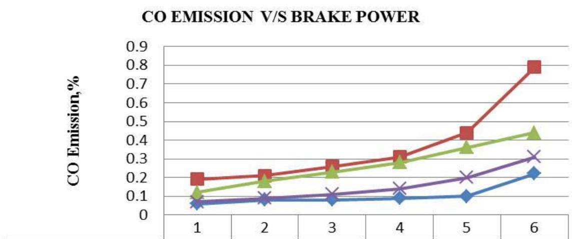


	1	2	3	4	5	6
Diesel	18	20	22	26	34	53
HOME	44	52	60	63	82	113
HOME+G25PPM	26	34	46	58	72	86
HOME+G50PPM	20	23	36	42	55	62

Figure 5: Variation of HC Emission with Brake power

3) Variation CO emission

Figure 6 shows variation CO emissions for diesel, HOME and HOME- GRAPHENE blended fuel. The CO emission for HOME operation was higher compared to diesel due to its lower thermal efficiency resulting in incomplete combustion. However CO emissions were marginally lower for the HOME- GRAPHENE blended fuels than HOME. The higher catalytic activity and improved combustion characteristics of GRAPHENE NPs and leading to improved combustion could be the reason for this performance.



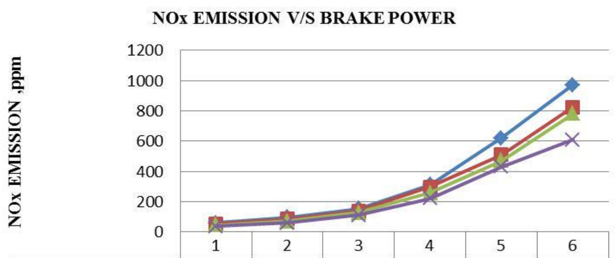
	1	2	3	4	5	6
Diesel	0.06	0.08	0.08	0.09	0.1	0.22
HOME	0.19	0.21	0.26	0.31	0.44	0.79
HOME+G25PPM	0.12	0.18	0.23	0.28	0.36	0.44
HOME+G50PPM	0.07	0.09	0.11	0.14	0.2	0.31

Figure 6: Variation of CO Emission with Brake power

HOME+50 GRAPHENE showed the better results as compared to HOME+25 GRAPHENE fuel due to the increased dosing level of GRAPHENE nanoparticles that facilitates complete combustion of fuel inside the engine.

4) Variation of NOx emission

Figure 7 shows variation of NOx emission for diesel, HOME and HOME+GRAPHENE blended fuels. HOME shows lower NOx emissions compared to diesel operation. Heat release rates of HOME were lower during premixed combustion phase, with lower peak temperatures prevailing inside the combustion chamber. Nitrogen oxides formation strongly depends on the peak temperature, which explains the observed phenomenon. Furthermore, HOME+GRAPHENE nano particles blended fuels produced lower NOx emission compared to that of HOME. This could also be due to higher premixed combustion observed with HOME+GRAPHENE nanoparticles blends. The HOME+50 GRAPHENE shows lower NOx compared to the HOME+25 GRAPHENE.

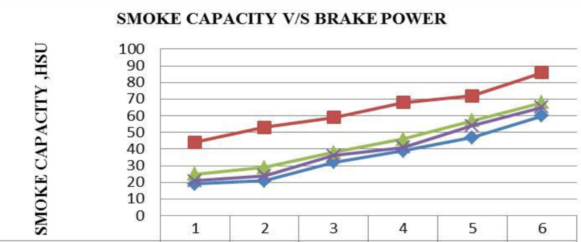


	1	2	3	4	5	6
Diesel	58	96	152	312	620	970
HOME	53	85	139	298	510	825
HOME+G25PPM	46	72	128	258	470	780
HOME+G50PPM	38	60	110	220	430	610

Figure 7: Variation of NOx Emission with Brake power

5) Variation of smoke opacity

Figure 8 variation of smoke opacity for Diesel, HOME and HOME+GRAPHENE blended fuels. The HOME results in little higher smoke opacity compared to diesel due to its heavier molecular structure and lower volatility. However reduced smoke opacity is observed in the case of HOME+ GRAPHENE blended fuels. This could be attributed to shorter ignition delay characteristics of HOME+GRAPHENE blended fuels.



	1	2	3	4	5	6
Diesel	19	21	32	39	47	60
HOME	44	53	59	68	72	86
HOME+G25PPM	25	29	38	46	57	68
HOME+G50PPM	21	24	36	41	54	65

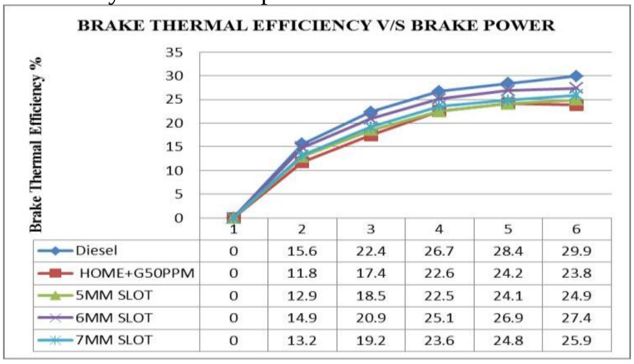
Figure 8: Variation of smoke capacity with Brake power

Moreover, in case of HOME+50 GRAPHENE fuel, the molecular structure and volatility may have enhanced due to the high dosage of compared to that of HOME+25 GRAPHENE. Due to this effect, smoke opacity is lower for HOME+50 GRAPHENE compared to that of HOME+25 GRAPHENE.

B. Effect of swirl on CI engine

1) Variation of brake thermal efficiency

Figure 9 shows variation of brake thermal efficiency for different slot widths provided on the piston surface using HOME+50 GRAPHENE blended fuels. The HOME+50 GRAPHENE with plain piston surface slot resulted in inferior performance. However brake thermal efficiency of the HOME+50 GRAPHENE blended fuels with swirl assisted by slots improved compared to neat HOME+ 50 GRAPHENE operations. This could probably be attributed to the better mixing of fuel and air in the combustion chamber cylinder. The HOME+50 GRAPHENE + 6 mm slot showed improved performance as compared to the other two slots of 5mm and 7mm due to the better mixing effect induced by swirl and improved combustion of fuel.

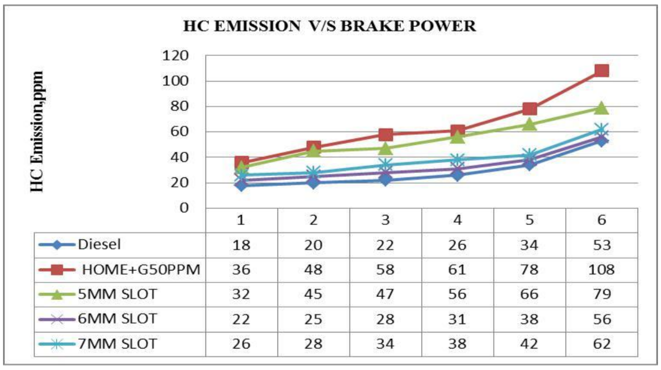


	1	2	3	4	5	6
Diesel	0	15.6	22.4	26.7	28.4	29.9
HOME+G50PPM	0	11.8	17.4	22.6	24.2	23.8
5MM SLOT	0	12.9	18.5	22.5	24.1	24.9
6MM SLOT	0	14.9	20.9	25.1	26.9	27.4
7MM SLOT	0	13.2	19.2	23.6	24.8	25.9

Figure 9: Variation of Brake Thermal Efficiency with Brake power

2) Variation of HC emission

Figure 10 shows the behaviour unburnt HC emission for different slot widths provided on the piston surface using HOME+50 GRAPHENE blended. The HC emission for HOME+ 50 GRAPHENE operations in all modes is higher compared to diesel due to its lower thermal efficiency. However HC emissions are marginally lower for the HOME+50 GRAPHENE +SLOTS blended fuels than HOME. This could be due to increased catalytic activity and improved combustion characteristics of GRAPHENE NPs and better mixing of air-fuel in combustion chamber, which lead to improved combustion. TheHOME+50 GRAPHENE + 6 mm slot showed lower UBHC emission as compared to the other two slots of 5 mm and 7 mm.

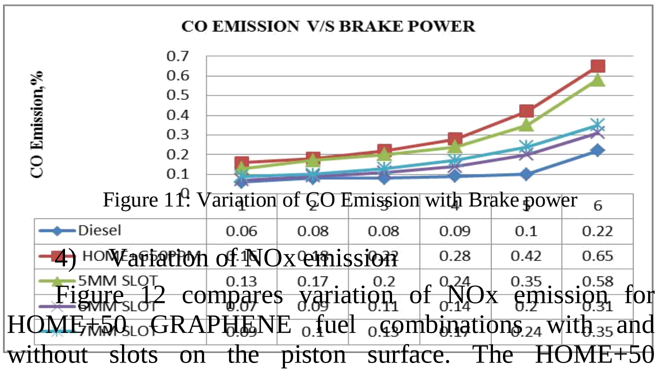


	1	2	3	4	5	6
Diesel	18	20	22	26	34	53
HOME+G50PPM	36	48	58	61	78	108
5MM SLOT	32	45	47	56	66	79
6MM SLOT	22	25	28	31	38	56
7MM SLOT	26	28	34	38	42	62

Figure 10: Variation of HC Emission with Brake power

3) Variation CO emission

Figure 11 shows the variations CO emission for HOME+50 GRAPHENE fuel combinations with and without slots on the piston. The CO emission for HOME+ 50 GRAPHENE operations is higher compared to HOME+50 GRAPHENE +SLOTS due to its lower thermal efficiency with incomplete combustion. However CO emissions are marginally lower for the HOME+50 GRAPHENE +SLOTS blended fuels than HOME+50 GRAPHENE. The higher catalytic activity and improved combustion characteristics of silver NPs combined with swirl induction probably lead to improved mixing of fuel and hence in the resulting behavior. The CO emission of HOME+50 GRAPHENE + 6 mm slot was much lower than that of as compared to the other two slots of 5mm and 7 mm.

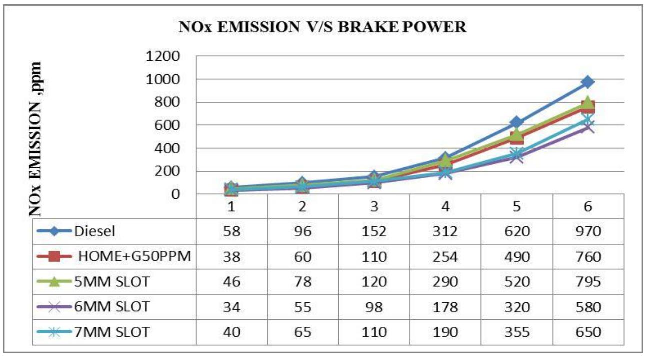


	1	2	3	4	5	6
Diesel	0.06	0.08	0.08	0.09	0.1	0.22
HOME+G50PPM	0.16	0.18	0.22	0.28	0.42	0.65
5MM SLOT	0.13	0.17	0.2	0.24	0.35	0.58
6MM SLOT	0.07	0.09	0.11	0.14	0.2	0.31
7MM SLOT	0.09	0.1	0.13	0.17	0.24	0.35

Figure 11: Variation of CO Emission with Brake power

4) Variation of NOx emission

Figure 12 compares variation of NOx emission for HOME+50 GRAPHENE fuel combinations with and without slots on the piston surface. The HOME+50 GRAPHENE showed lower NOx emissions compared to diesel operation. NOx emission of HOME+50 GRAPHENE + 6 mm slot was much higher than that observed for 5mm and 7 mm slots. This could be due to more heat release rate obtained during premixed combustion for 6 mm slot operation.

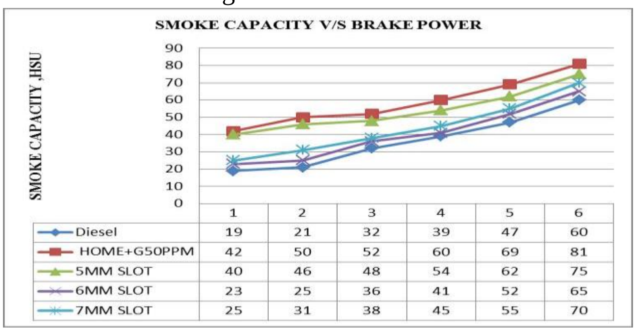


	1	2	3	4	5	6
Diesel	58	96	152	312	620	970
HOME+G50PPM	38	60	110	254	490	760
5MM SLOT	46	78	120	290	520	795
6MM SLOT	34	55	98	178	320	580
7MM SLOT	40	65	110	190	355	650

Figure 12: Variation of NOx Emission with Brake power

5) Variation of Smoke opacity

Figure 13 shows the variation of smoke for HOME+50 GRAPHENE fuel combinations with and without slots on the piston surface. The smoke opacity for HOME+50 GRAPHENE +SLOTS shows the lower compared to the HOME+50 GRAPHENE and HOME operation. This is due to its higher catalytic activity and improved combustion characteristics of GRAPHENE NPs combined with swirl induction probably lead to improved mixing of fuel and hence in the resulting behaviour.



	1	2	3	4	5	6
Diesel	19	21	32	39	47	60
HOME+G50PPM	42	50	52	60	69	81
5MM SLOT	40	46	48	54	62	75
6MM SLOT	23	25	36	41	52	65
7MM SLOT	25	31	38	45	55	70

Figure 13: Variation of smoke capacity with Brake power

The smoke opacity emission of HOME+50 GRAPHENE + 6 mm slot was much lower than that of as compared to the other two slots of 5 mm and 7 mm.

V. CONCLUSIONS

From the exhaustive experimental investigation on single-cylinder, constant speed, direct-injection diesel engine fuelled with graphene nanoparticles - HOME fuels, with and without the effect of swirl. Based on the experimentation data, the following conclusions were drawn.

1. Use of HOME in diesel engine provides complete independence from petroleum fuel resources. HOME shows poor results in terms of reduced brake thermal efficiency, and increased emission of smoke, Hydrocarbons and carbon monoxides.
2. Addition of Graphene nanoparticles to HOME enhances the combustion characteristics and catalytic activity of the fuel, and thereby reduces the emissions and ignition delay during combustion process.
3. HOME+50GRAPHENE blended fuel shows better results as compared to the HOME+25 GRAPHENE and Diesel blended fuel in terms of increased Brake thermal efficiency and reduced emission of smoke, Hydrocarbons, carbon monoxide.
4. HOME+50GRAPHENE blended fuel with 6mm slot on piston crown shows better results as compared to the HOME+50GRAPHENE with 5mm slot and HOME+50 GRAPHENE with 7mm in terms of increased Brake thermal efficiency and reduced emission of smoke, Hydrocarbons, carbon monoxide.
5. A nitric oxide emission of HOME+50 GRAPHENE was lower compared to HOME+25 GRAPHENE, HOME and Diesel fuel.
6. Nitric oxide emissions of HOME+50GRAPHENE with 6 mm slot on piston crown was lower compared to HOME+50 GRAPHENE+5mm and HOME+50 GRAPHENE+7mm.
7. Effect of swirl with tangential slots provision on the piston surface showed better results and reduced emissions. 6 mm slot was found to be optimum.

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