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Performance and Emission Features of Diesel-Silicon Dioxide (SiO2) Nanoparticles Fuelled Operated VCR Diesel Engine

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Abstract. An experimental investigation was accomplished for the effect of SiO2 nanoparticles (SNP) addition on performance and emissions features of a four-stroke single cylinder variable compression ratio diesel engine. The SNP were mixed with pure diesel in a dosage of 5mg, 10mg, 15mg, 20mg, and 25mg. These test fuels were tested at various engine loads of 2kW, 4kW, 6kW, 8kW, 10kW and 12kW at a speed of 1500 rpm with 18 C.R. The results shows that the maximum enhancement in brake thermal efficiency (BTE) achieved was 15.16% and minimum reduction of 14.28% in brake specific fuel consumption (BSFC) was noticed when correlated to neat diesel fuel at full load condition. The emissions of NOX, CO, HC, and smoke opacity (PM) for 20Si600DF (20 mg SNP+20mg CTAB+600 ml diesel) test fuel were significantly decreased by 77.13%, 82.14%, 93.94%, and 33.41% as compared to pure diesel fuel at full load condition. The results reported that 20Si600DF at 18 CR value shows the optimal improvement in performance with minimum emissions. Finally, it can be concluded that SiO2 nanoparticles act as a promising additive which can be added in diesel fuel in order to reduce emissions and enhance performance parameters without any engine modifications.

Keywords **:** ***Nanoparticles, Diesel Engine etc.***

I. INTRODUCTION

Over the last few years, the environmental pollution from diesel engines has become a major issue as the emissions released out from the exhaust of diesel engines are harmful [1]. Therefore, to safeguard our environment from the ill effects of emissions from diesel engines, the researchers are continuously searching for alternative fuels.

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One such form of substitute fuel for diesel is the addition of nanoparticles in diesel fuel [2]. There exist numerous advantages associated with nanoparticles usage in diesel engines. Some of them are an immense surface area-volume ratio, excessive energy density, noteworthy shortening of ignition delay, enhanced evaporation rate and superior atomization [3]. All these properties of nanoparticles result in the greater release of heat and pressure inside the cylinder. Thus, nanoparticles improve evaporation and combustion features related to diesel engines by behaving like a perfect catalyst [4].The effect of titanium dioxide (TiO2) nanoparticles addition to diesel, biodiesel and n-butanol blends was also examined [5]. The researchers reported that by the incorporation of TiO2 nanoparticles, BSFC reduces and brake engine torque increases whereas NOX emissions were increased. Graphenenanoplatelet (GNP) was added to jatropha biodiesel-diesel blend for evaluating performance and emissions [6]. They observed that BTE was enhanced whereas BSFC was reduced. The emissions of NOX, CO and HC were reduced. The use of TiO2, copper nitrate and cerium acetate hydrate nanoparticles in pure diesel fuel for emission analysis of diesel engines [3]. They revealed that CO and HC emissions were maximum reduced by the incorporation of cerium acetate hydrate nanoparticles as compared to diesel fuel, but simultaneously NOX emissions increased due to an increase in temperature. The nanofluid containing nanoparticles of ZnO and TiO2were mixed with Calophylluminophyllum biodiesel for further analysis [7]. They observed that the blends show a lower value of BTE and higher BSFC as compared to diesel. Also, HC, CO and PM emissions were decreased but NOX emissions were found out to be increased by 40% higher than that of diesel fuel.

Although few experimental analysis were conducted for analyzing the performance and emission features of diesel engine, almost all were based on adding nanoparticles in a diesel-biodiesel blend, which resulted in increment of NOX emissions.Here, in this study SiO2 nanoparticles were added in pure diesel instead of biodiesel for enhancing performance and reducing the emissions level of CO, HC, PM and NOX as well.

II. MATERIALS AND METHODS

2.1. Materials

For carrying out various experiments SiO_2 nanoparticles were purchased from Ultrananotech, India with particle size 30-50 nm, surface specific area 120-150 m2/g with white color appearance. Figure1 shows the TEM image of SiO_2 nanoparticles and CTAB was used as a surfactant and was procured from Scientific Chemical, India. High-speed diesel was procured from the local fuel station of HP fuel station.

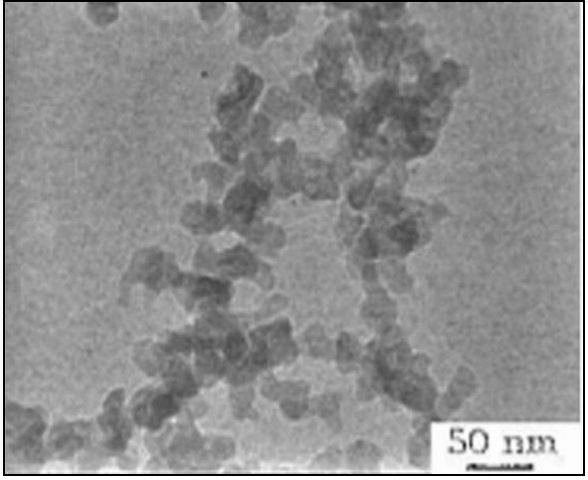

Figure 1.TEM image of SiO2 nanoparticle

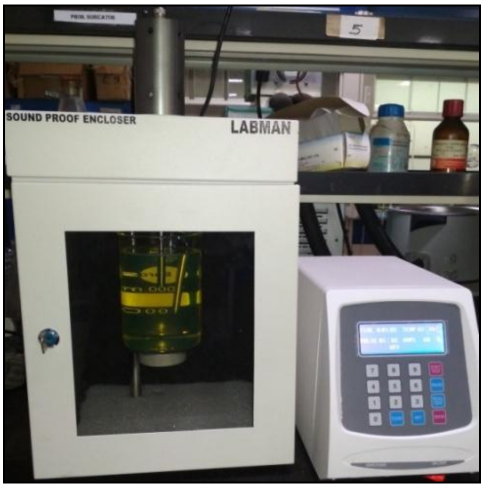

Figure 2. Ultrasonication

2.2. Preparation of test fuels

For various test fuels preparation, the chosen quantity of SiO_2 nanoparticles (5mg to 25mg, with an equal interval of 5) and similarly CTAB (5mg to 25mg, with an equal interval of 5) were added to base diesel fuel. For better dispersion of SNP in diesel, the magnetic stirrer technique was used for 30 minutes at 1000 RPM and then Ultrasonication was done by using probe-type sonicator for 30 minutes at 20 kHz frequency. The test fuels were labelled as 5Si900DF (5mg SNP+5mg CTAB+900ml DF), 10Si800DF (10mg SNP+10mg CTAB+800ml DF), 15Si700DF (15mg SNP+15mg CTAB+700ml DF), 20Si600DF (20mg SNP+20mg CTAB+600ml DF) and 25Si500DF (25mg SNP+25mg CTAB+500ml DF) respectively. The sample of prepared test fuel 5Si900DF is shown in figure 2.

2.3. Diesel engine and experimental procedures

All the experiments were showed by using 4- stroke, single cylinder, with compression ration ranging from 12-18. The general specifications of the test engine are tabulated in Table 1. The simplified layout of the experiment is represented in figure 3. The engine was conjoined with eddy current dynamometer (Model TMEC-10, max.7.5 kW, RPM 1500-5000). In order to measure smoke opacity, AVL 437C smokemeter was utilized. For the emission measurement of NOX, HC and CO an exhaust gas analyzer of AVL DIGAS 444N was used. All the main equipment used in the experimental work are shown in figure 4 and figure 5. For the achievement of steady-state conditions, all the outcomes of various experiments are noted after continuous operating the engine for 30 minutes.

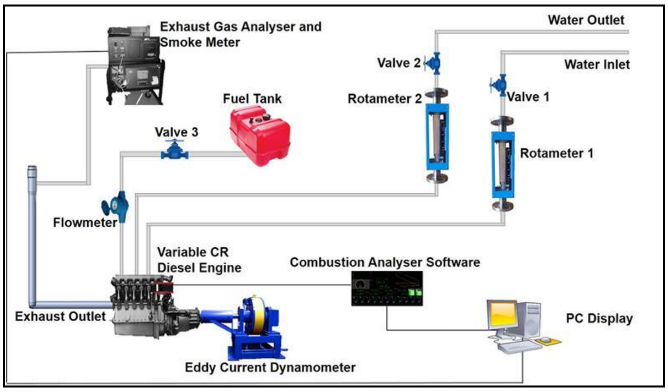

Figure 3. Simplified layout of the experiment

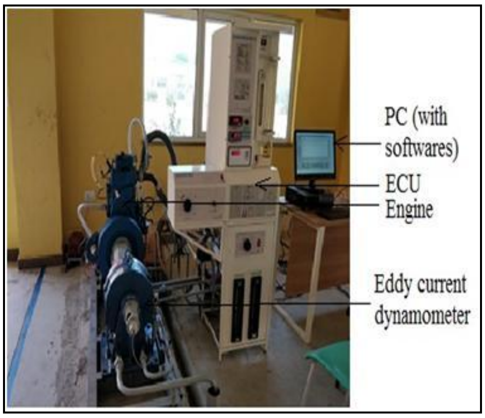

Figure 4. Research engine test rig

Table1. General specifications of test engine

Parameters	Details
No. of cylinder	1
Strokes	4
Make/model number	Apex Innovation 240PE
Bore	87.5 mm
Length of stroke	110 mm
Connecting rod length	234 mm
Rated power	3.5 kW
Rated speed	1500 RPM
Cooling method	Water cooled
Compression ratio	12:1-18:1

Injection variation	0-25° BTDC
Dynamometer	Eddy current type
Arm length	185 mm
Diameter of orifice	20 mm
Software for performance analysis	'Enginesoft' supplied by Apex Innovation, India

Table2. Uncertainty percentage

Measurements and their range	Resolution	% uncertainty
Load (0-12 kg)	2 kg	±0.19%
BSFC	---	±1.2%
BTE	---	±1.2%
Fuel flow measurement (0-100 ml)	±1 ml	±1%
CO emission (0-15%vol)	0.01%vol	± 0.06%
CO_2 emission (0-20%vol)	0.1%vol	± 0.5%
HC emission (0-30000 ppm)	1 ppm	± 0.3%
O_2 emission (0-25%vol)	0.01%vol	± 0.04%
NO_X emission (0-5000 ppm)	1 ppm	± 0.02%
Smoke opacity (0-100%)	0.10%	± 0.1%
Engine speed(400-6000 rpm)	10 rpm	± 0.167%

Figure 5.5gas analyzer and Smokemeter

The experimental procedure includes preparation of various test fuels using SNP-DF combination such as 5Si900DF, 10Si800DF, 15Si700DF, 20Si600DF and 25Si500DF. These test fuels were utilized to run the VCR engine. The performance parameters and emissions values were recorded at all load conditions of 2-12 kW (with an equal interval of 2) at 18 compression ratio with a fixed engine speed of 1500 RPM. The optimal test fuel among the various SNP-DF combinations was then selected which results in better performance among different prepared fuels and minimum emissions without any engine modifications. So, the performance and emissions features of variable compression ratio diesel engine will be monitored when the engine is fuelled with silicon dioxide nanoparticles-diesel fuel combinations. The obtained results will be compared by using only pure diesel as a fuel in the same engine under similar operating conditions.

2.4. Uncertainty analysis

The current experimental work involves uncertainties as well as errors because of environmental conditions, improper adjustments, inaccuracy in inspection and calibration. The root mean square approach is used to evaluate the degree of uncertainty and it is represented in Table 2. The overall experimental uncertainty came out to be ±2.28%.

III. RESULTS AND DISCUSSIONS

3.1. Performance measurements: Brake thermal efficiency (BTE) and Brake specific fuel consumption (BSFC)

The difference between BTE and load for diesel and all the ready test fuels is shown in figure 6. It is noticed that as the load increases, there is a minimal improvement of BTE with SNP-diesel test fuels. It is observed that BTE for pure diesel fuel is 31.78% at full load (12kW) whereas with 20Si600DF and 25Si500DF the value of BTE is 36.39 % and 36.60 % respectively. This could be attributed to the actuality that nanoparticles acquire huge surface area-volume ratio which results in fine atomization and accelerates the evaporation of fuel which improves BTE [8]. As the concentration of SNP in diesel is increased, the flame temperature due to complete combustion also increases, thereby boosting the BTE [9]. The similar trends of BTE were reported by other researchers [10, 6]. The increment in BTE was observed to be 14.5% by 20Si600DF and by 15.16% by 25Si500DF as compared to normal diesel BTE at full load condition.

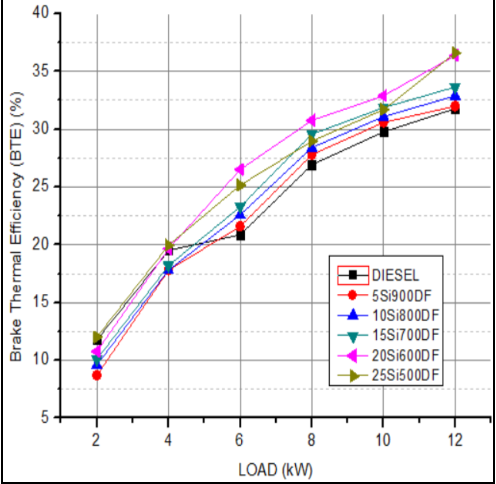

Figure 6.Variation betweenBTE and load

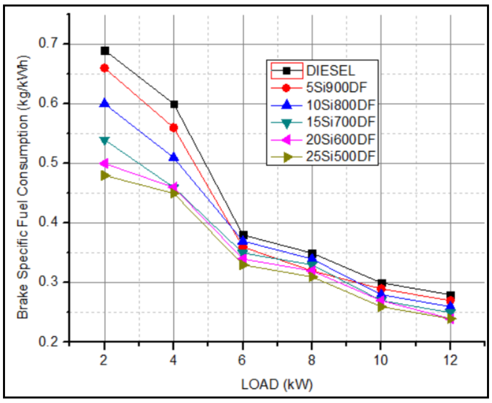

Figure 7.Variation betweenBSFC and load

The change of BSFC with load is shown in figure 7. It can be seen that the BSFC for diesel fuel at full load condition is 0.28 kg/kWh, whereas for both 20Si600DF and 25Si500DF the value is 0.24 kg/kWh. The BSFC declines by up to 14.28% by the use of silicon dioxide nanoparticles-diesel fuel as compared to only diesel fuel. As the load increases, the specific fuel consumption decreases. The scaling down of BSFC is due to the agile rate of burning and greater release of heat [11]. Shorten ignition delay attributes also contributes to low BSFC when SNP is added to DF and also due to the catalytic action of nanoparticles, the combustion process is upgraded and hence the fuel consumption of all the prepared test fuels reduces as the load increases [1]. The reported BSFC trends were similar to the studies conducted by [3, 5]. Here, both fuels such as 20ZnO60DF and 25ZnO50DF show similar values for BSFC.

3.2. Emission measurements

3.2.1.NOX emissions. The alterations recorded in NOX emissions for different test fuels at varying load conditions are depicted in figure 8. It can be clearly observed that diesel fuel acquire greater NOX emission features. At 12 kW load, the NOX emissions for diesel was found to be 1841 ppm whereas for 20Si600DF and 25Si500DF it was 421 ppm and 468 ppm respectively. The test fuel 20Si600DF shows the minimum emission of NOX at maximum load condition. This could be attributed to the fact that lessened ignition delay period and rich catalytic action of nanoparticles results in a complete combustion process [7]. Also, the metal oxide nanoparticle takes the oxygen for declination of NOX emissions [12]. Moreover, nanoparticles reduce the temperature inside the combustion chamber as they behave as a heat sink and this keeps away the regions of hot spots, thereby lowering the formation of NOX [13]. The similar trends were also reported by other researchers also [14, 15]. Here, the NOX emissions decreased by up to 77.13% for 20Si600DF at full load as compared to normal diesel fuel emissions.

3.2.2.Smoke opacity (PM) emissions. The variations of smoke emissions for diesel and different test fuels are shown in figure 9. It is observed that smoke emissions hike as the load enhances and consequently some extra fuel is supplied inside the cylinder for achieving the same power output. At 12 kW load, the smoke opacity was recorded as 78.1 HSU for diesel while for 20Si600DF and 25Si500DF it was found to be 52 and 60.7 respectively. Low smoke emissions result in complete combustion due to the oxygen content of SNP [7]. SiO2 nanoparticles enhance the oxidation of unburned hydrocarbons and PM which results in faster evaporation [16]. Due to the lower ignition timing, the premixed combustion phase shortens down, which ultimately results in lower soot emissions [12, 17]. These observations regarding PM emissions are good in agreement with many other researchers [8, 18, 19]. Here, the PM emissions decreased by up to 33.41% for 20Si600DF at full load as compared to normal diesel fuel emissions.

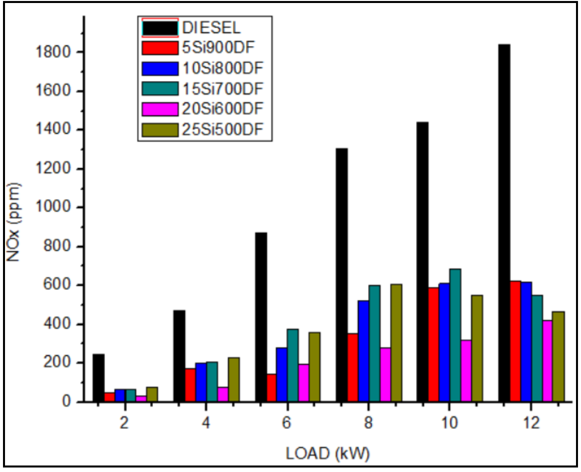

Figure 8.Variation between NOX and load

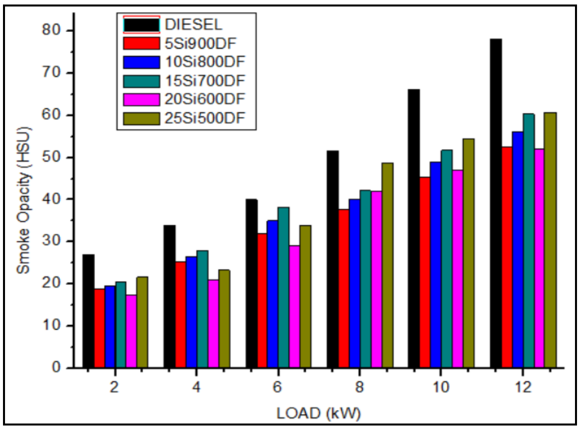

Figure 9.Variation betweenPM and load

3.2.3. CO emissions.The basic sources of formation of CO emissions are weak mixing as well as imperfect combustion [20]. Figure 10 represents the variations between CO emission and load for diesel and other test fuels. As noticed in figure 10 that CO emission declines with increases in load. At 12 kW load, CO emissions in % volume were found to be 0.056, 0.01 and 0.01 respectively for diesel, 20Si600DF and 25Si500DF. The CO emissions were greatly reduced by up to 82.14% for 20Si600DF and 25Si500DF test fuels as compared to normal diesel fuel CO emissions at full load condition. This can be because of the extra percentage of oxygen in SNP which behave as oxidation catalyst which speeds up the process of combustion and converts the carbon monoxide into carbon dioxide [7, 20].

Due to the incorporation of nanoparticles in diesel fuel, the burning reactions boost up which in turn causes lessening of the ignition delay period. Moreover, the complete burning of fuel lessens the emissions of CO as compared to neat diesel fuel in diesel engines [8]. These outcomes related to CO emissions are in coordination with the findings of other researchers also [9, 21, 22].

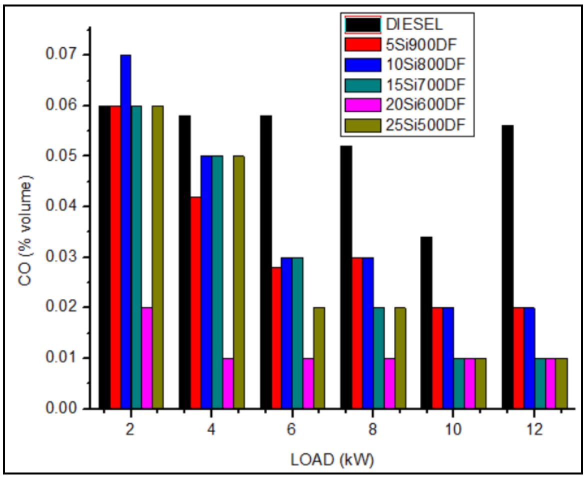

Figure 10.Variation betweenCO and load

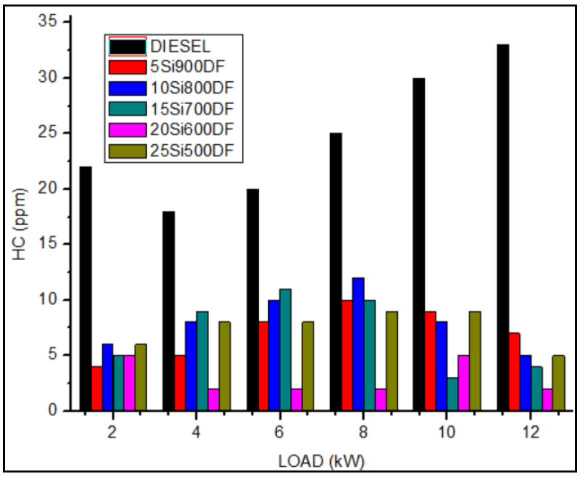

Figure 11.Variation betweenHC and load

3.2.4. HC emissions. The deviations between HC emission and load by using prepared fuels are illustrated through figure 11. The hydrocarbon emission is equipped with unburned fuel due to an insufficient temperature near the wall of the cylinder [23]. At full load condition, the HC emission for diesel fuel is highest as compared to all other test fuels. The main reason is incomplete combustion and lower BTE value for diesel fuel [3]. At 12 kW the hydrocarbon emissions in ppm were found out to be 33, 7, 5, 4, 2 and 5 for DF, 5Si900DF, 10Si800DF, 15Si700DF, 20Si600DF and 25Si500DF respectively. It was noticed that the maximum reduction of 93.94% was reported with 20Si600DF test fuel. The silicon dioxide nanoparticles reduce the ignition delay period because of their improved catalytic action and therefore the infusing of fuel particles with air gets accelerated [24]. SiO2 nanoparticle incorporated diesel test fuels shows lower HC emissions because of improved combustion characteristics and enhanced catalytic activity of nanoparticles [25, 26]. The reported results are good in agreement with [3, 6, 7, 12, 17, 27].

IV. CONCLUSION

In this work, the performance and emission features of the VCR diesel engine was investigated by using silicon dioxide nanoparticle incorporated diesel fuel at a fixed compression ratio of 18. It was noticed that BTE was improved whereas BSFC was reduced by the addition of SiO2 nanoparticles to the diesel fuel at full load condition when compared to neat diesel as a fuel in a diesel engine. All the major emissions such as NOX, PM, CO, and HC were also greatly reduced by the addition of SiO2 nanoparticles to diesel fuel at full load condition when compared to the emissions by using neat diesel as a fuel in a diesel engine. It is because nanoparticles lead to complete combustion and shorter ignition delay. The test fuel 20Si600DF possesses noteworthy emissions level thereby making it suitable as eco-friendly fuel. In general, it has been concluded that silicon dioxide nanoparticles addition to diesel could be accepted as a clean alternative fuel for diesel engines as it enhances the engine performance and reduces all the harmful emissions to a great level without any engine modifications. The maximum reduction in emissions is primarily important as this proves to be environmentally friendly. However, future studies should be executed for analyzing the effects of nanoparticles on the wear of engine parts. Also, the after effects of nanoparticles when released in air through engine exhaust should be critically examined.

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Nomenclature

ASTM : American society of testing and materials
BSFC : Brake specific fuel consumption
BTE : Brake thermal efficiency
DF : Diesel fuel
HC : Hydrocarbon
NOX : Nitrogen oxide
PM : Particulate matter
VCR : Variable compression ratio
SNP : Zinc oxide nanoparticle
5Si900DF: 5 mg SNP+5 mg CTAB+900 ml DF
10Si800DF: 10mg SNP+10 mg CTAB+800 ml DF
15ZnO70DF: 15 mg SNP+15 mg CTAB+700 ml DF
20ZnO60DF: 20 mg SNP+20mg CTAB+600 ml DF
25ZnO50DF: 25 mg ZNP+25 mg CTAB+500 ml DF

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