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Original Research Article

Experiment and Prediction of the Effects of Acetoacetic Ester, CuO and $CuSO_4$ Nanometals on the Emission and Performance Characteristics of a CI Engine Run With Watermelon Seed Oil Methyl Ester-Diesel Blends

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Abstract

The performance and emission characteristics of a stationary four-cylinder, four-stroke, compression ignition (CI) diesel engine have been studied at 2000 rpm with pure diesel and watermelon seed oil methyl ester (WOME)-diesel (D80) blends with the additives acetoacetic ester, CuO and $CuSO_4$ nanoparticles. A three-level factorial design was used to determine the quantity of WOME and the additives mixed with D80 in the experimental runs. The emission (H_2S, NO_2, CO and exhaust gas temperature (EGT)) and performance (fuel consumption (FC), brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE)) properties were very much improved above WOME20D80. The emission properties were also better than diesel, except NO_2 that was higher by 6.3 %. The performance properties were much better than WOME20D80 but not as good as diesel. Compared with diesel FC was 11.4 % higher, BSFC 11.4% higher and BTE was 4.3 % lower. These emission and performance values are better than most of what had been reported in the literature; the acetoacetic ester provided additional oxygen to ease combustion. The experimental data have been fitted to a second-order polynomial equation and subjected to analysis of variance leading to some equations that may help predict the emission and performance properties of CI engines.

Keywords: Acetoacetic ester, Copper (II) Oxide, Copper (II)Sulphate nanoparticles, Watermelon seed oil methyl ester, Diesel blends, Emissions, Performance.

1. INTRODUCTION

The search for alternative fuels to conventional fuels has been propelled by the limited availability of fossil fuels and their negative impact on the environment. Biodiesel from different sources has drawn greater attention than any other alternative fuel because it is non-toxic, biodegradable and renewable (Arthab M. I *et al*. 2013). It is also believed to act as a lubricant, reducing wear and increasing pump life when used as fuel for an internal combustion engine (Panneerselvam N. *et al*. 2017). However, biodiesel has a high viscosity, low oxidation stability, low volatility, high pour point, low calorific value and high NOx emission, which adversely affect the performance of diesel engines (Karthikeyen S. *et al*. 2014). Among the methods adopted to improve engine performance include engine modification, fuel modification and exhaust gas treatment. Engine modification is expensive and an arduous task since it entails changing injection timing, valve timing, compression ratio, and providing anti-wear coatings or linings for the inner parts. Fuel modification with additive(s) is preferred because it is cheaper, yet it improves performance and emission properties (Attia A. M. A *et al*. 2015; Syed Aalam C. *et al*. 2015; D'Silva R. *et al*. 2017; Sahoo P. K *et al*. 2009; Babu K. R and Raja R. B 2015).

Several researchers have shown that the performance and emission characteristics of biodiesel can be improved by the dispersion of nanomaterials into it. The nanomaterials enhance the thermophysical properties of the biodiesel due to their physical, thermal and catalytic properties, and are known to offer a large contact surface area during the oxidation process (Sahoo P. K *et al*. 2009; Babu K. R and Raja R. B 2015). Soner G. *et al*. (2016) in their investigation of petroleum diesel blended with Al_2O_3 and CuO in a single-cylinder four-stroke water-cooled DI diesel engine obtained 13%, 11% and 6% reduction in unburned hydrocarbons (UBHC), CO, NO_x

respectively. Balaji G. and Cheralathan M. (2015) achieved an 8.56% and 2.8% reduction in the emission of CO and NO_2 respectively when they blended neem seed oil methyl ester with carbon nanotube (CNT), and the brake thermal efficiency (BTE) increased between 2.12% and 4.17% depending on the concentration of CNT. Naik J.V and Kumar K.K (2018) working on a four-stroke single-cylinder CI engine using Al_2O_3 nano diesel achieved 13.3%, 12.17% and 8.75% reduction in UBHC, CO and NO_x and with CuO, nano diesel had 6.3%, 7.11% and 2.6% emissions reduction of UBHC, CO and NOx respectively compared with pure diesel; they also obtained a reduction in the brake specific fuel consumption (BSFC) by 1.4% and 0.65% respectively. Varying degrees of improvement has been obtained by other researchers.

Watermelon (*Citrullus lanatus*) is planted mainly for its juice, nectars and fruit; recently, the seeds which are eaten in some countries but not in Nigeria are said to be rich in protein and lipids (Yaliwal V. S *et al.* 2016). Harari P. A (2017) working with various blends of watermelon seed oil found B20 to give the best engine performance and reduced emissions, thus we have chosen B20 watermelon seed oil methyl ester (WOME) with D80 diesel for modification with Acetoacetic ester (Ace) and the nanoparticles of CuO and $CuSO_4$. Based on a 3-level factorial design that provided for thirty-two experimental runs, the concentrations of the additives, acetoacetic ester and the nanoparticles of CuO and $CuSO_4$ were varied. The additives-blends were used to run a compression ignition (CI) diesel engine to determine the optimal engine emissions and performance, and assess the significant contribution of the third component acetoacetic ester.

Also, the design expert software 11 has been deployed in the analysis of the experimental data to generate equations that may be used to predict emission and performance properties of CI engines with WOME20D80.

2. MATERIALS AND METHODS

2.1 Extraction of oil and production of watermelon seed oil methyl ester (WOME)

The watermelon seeds were extracted from the watermelon fruits and washed to remove impurities. The wet seeds were sun-dried for 7 days to reduce the moisture content and milled to small particle size to increase the surface area, then the oil extracted with n-hexane in a Soxhlet extractor. The optimal conditions established by Panneerselvam N. *et al*. (2017) for the preparation of watermelon seed oil methyl ester (WOME) were adopted as follows: agitation speed 550 rpm, reaction temperature 60℃, reaction time 55 mins, methanol to oil ratio 20 vol % and 13 g of KOH pellet per 2.5 litres of oil. The properties of the biodiesel (WOME) produced were tested by standard methods and are shown in table 1.

2.2 Experimental design

WOME20D80 served as the control, while other blends were based on the values generated using the three-level factorial design of design expert 11 statistical packages. The three levels for CuO and $CuSO_4$ were 10, 30 and 50mg/kg, but 1, 5 and 9 vol. % for acetoacetic ester; the difference of the 20vol % was made up with the biodiesel (WOME) while maintaining a constant 80vol % of diesel. Table 2 shows the values of the additives used in the experiments with their levels in the bracket.

Table-1: WOME properties compared with standards

Properties	WOME produced	Petrol-diesel ASTMD Standard (ASTMD975)	Biodiesel (ASTMD6751)
Density(g/cm^3)	0.89	0.82-0.845	0.86-0.90
Kinematic viscosity(mm^2/sec)	3.134	1.9-4. 1	1.9-6.0
Free fatty acid(mg/g)	0.561	0.27	0.50 max
Acid value(mgKOH/g)	1. 122		0.50 max
Saponification value(mg/g)	263.53		
Iodine value(gI_2 / 100g)	44.00	128.5	130 max
Moisture content(%)	0.0399	0.05 max	0.05 max
Biodiesel yield (vol. %)	92.30		
Flashpoint(℃)	93	60-80	130-170
Cloud point(℃)	-5	-15 to -5	-3 to -12
Cetane number (CN)	57. 11	40-55	47-65

Table-2: Experimental design

Exp.	CuO (mg/kg)	$CuSO_4$ (mg/kg)	Acetoacetic ester(vol%)
1	10 (-1)	10 (-1)	9 (+1)
2	50 (+1)	10 (-1)	5 (0)
3	30 (0)	10 (-1)	5 (0)
4	10 (-1)	50 (+1)	9 (+1)
5	10 (-1)	30 (0)	5 (0)
6	10 (-1)	10 (-1)	5 (0)
7	50 (+1)	50 (+1)	9 (+1)
8	30 (0)	50 (+1)	5 (0)
9	30 (0)	30 (0)	9 (+1)
10	10 (-1)	50 (+1)	5 (0)
11	30 (0)	10 (-1)	9 (+1)
12	50 (+1)	30 (0)	5 (0)
13	50 (+1)	30 (0)	1 (-1)
14	10 (-1)	30 (0)	9 (+1)
15	30 (0)	30 (0)	5 (0)
16	30 (0)	30 (0)	5 (0)
17	50 (+1)	50 (+1)	1 (-1)
18	30 (0)	30 (0)	5 (0)
19	30 (0)	50 (+1)	9 (+1)
20	30 (0)	30 (0)	1 (-1)
21	30 (0)	30 (0)	5 (0)
22	30 (0)	10 (-1)	1 (-1)
23	10 (-1)	10 (-1)	1 (-1)
24	10 (-1)	30 (0)	1 (-1)
25	30 (0)	50 (+1)	1 (-1)
26	10 (-1)	50 (+1)	1 (-1)
27	30 (0)	30 (0)	5 (0)
28	50 (+1)	50 (+1)	5 (0)
29	50 (+1)	10 (-1)	1 (-1)
30	50 (+1)	10 (-1)	9 (+1)
31	30 (0)	30 (0)	5 (0)
32	50 (+1)	30 (0)	9 (+1)

A four-cylinder, four strokes, compression ignition (CI) diesel engine with specifications listed in Table 3 and at a constant load of 10 N was used for the emissions and performance tests.

Table-3: Test engine specifications

Make	Kirloskar
Type	Four-cylinder, four strokes, compression ignition diesel engine
Stroke	115mm
Bore	100mm
Compression ratio (CR)	20:1
Brake mean effective power (BMEP)	694KPA
Displacement volume	0.903 litres
Power output	11KW
Min. Speed	220rpm
Injector timing	180 +/-
Dynamometer	Eddy current, water-cooled with loading unit and varying speed

2.3 Engine emissions and performance tests

The CI engine was first run without load for 30 mins to stabilize it. Subsequently, the eddy current dynamometer connected to the engine provided a constant load of 10N, and tests were performed in line with ISO 8178-C18-modes test cycle D1 for off-road engines. The engine was then run with pure diesel at 2000rpm and the engine performance and emissions characteristics recorded. The emission results were read in real-time on a monitor as concentrations of pollutants(ppm): NO_x was with PGM-228, CO with AMPRO-2000 and H_2S with PT-207 detectors respectively, while the exhaust gas temperature (EGT) was determined with the Hungetech thermometer. The fuel consumption (FC) was measured by the calibrated burette method, and standard equations were used to calculate the brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). Subsequently, the control fuel (WOME20D80) and the thirty-two blends with additives were independently subjected to the same tests as the diesel. The schematic diagram for the experiment is shown in Figure 1. The results are shown in Tables 4,5 and 6.

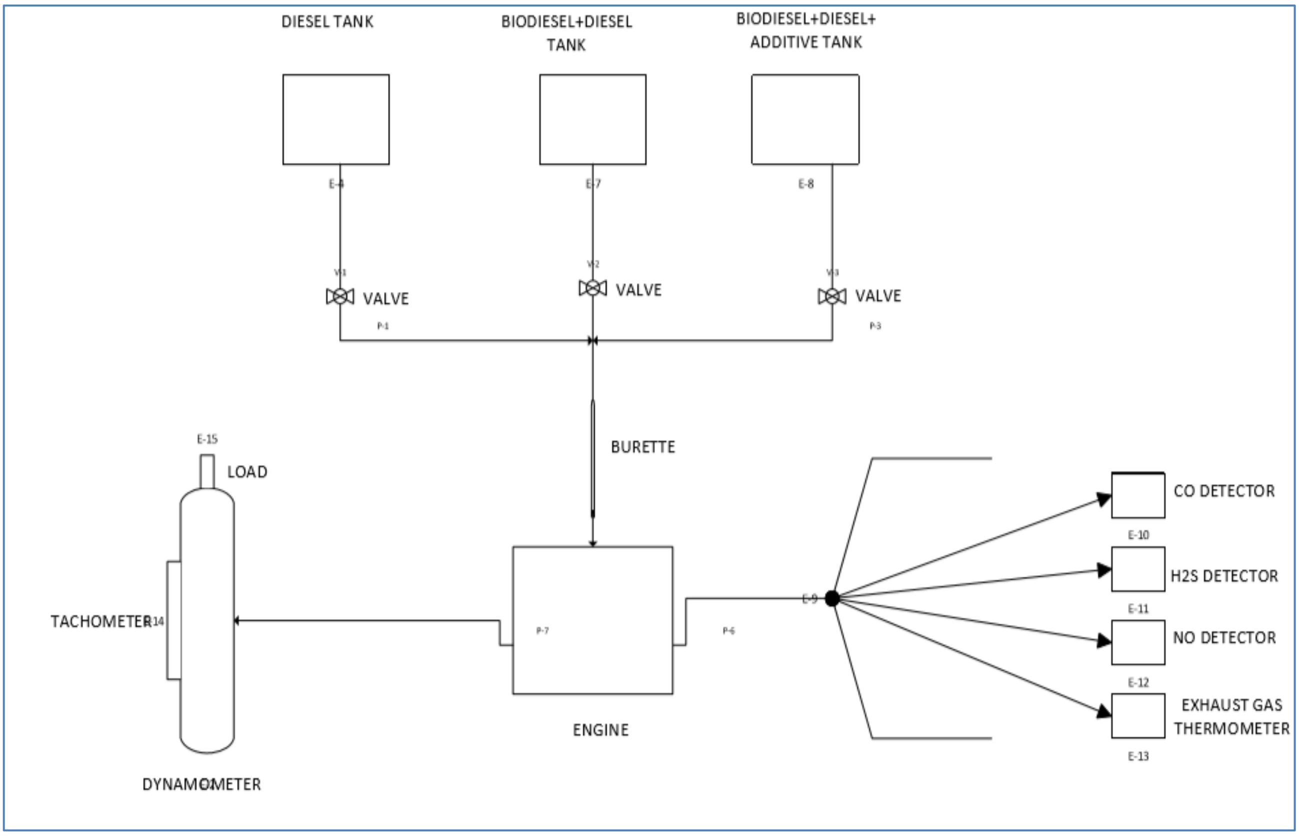

Fig-1: Schematic diagram for the experiment

3.0. RESULTS AND DISCUSSION

3.1 Properties of produced WOME

As shown in table 1, the density, kinematic viscosity, iodine value, saponification value, moisture content, cloud point and cetane number of the WOME met the ASTMD standard for biodiesel. The free fatty acid (FFA) of 0.561 mg/g was higher than the maximum of 0.5 mg/g for biodiesel. The flashpoint of 93 ℃ was outside the range of 130 ℃ -170 ℃ for biodiesels. Also, the acid value of 1.1222 (mg KOH/g) was higher than the maximum stipulated.

3.2. Engine emissions

From Tables 4 & 5, the NO_2 emission was least with pure diesel fuel while the optimal additives-blend WOME11D80Ace9CuO30Cu$SO_4$50 gave an improvement over the control blend (WOME20D80) but was still higher than diesel by 6.5%. NO_2 with the control blend was 22.4 % higher than with pure diesel.

Table-4: Engine emissions and performance with WOME20D80 blend and pure diesel

Emission/Performance Parameters	WOME20D80	Pure Diesel
H_2S (ppm)	1.14	1.74
NO_2(ppm)	232.71	190.12
CO (ppm)	69.13	74.24
EGT (^oC)	86.32	93.11
FC (l/hr)	1.70	1.140
BSFC (kg/kW.hr)	2.3016	1.5235
BTE (%)	4.01	5.35

Table-5: Engine emissions with additives

Exp.Run	Factor 1 A:CuO (mg/kg)	Factor 2 B:$CuSO_4$ (mg/kg)	Factor 3 C:Acetoacetic ester (vol. %)	H_2S (ppm)	NO_2 (ppm)	CO (ppm)	EGT (℃)
1	10	10	9	1.25	212.45	59.50	79.78
2	50	10	5	1.13	211.89	61.57	78.80
3	30	10	5	1.17	209.28	61.30	77.50
4	10	50	9	1.11	209.53	56.04	78.62
5	10	30	5	1.28	210.66	61.15	78.54
6	10	10	5	1.35	214.04	61.61	80.60
7	50	50	9	0.96	202.60	55.35	74.01
8	30	50	5	1.04	204.27	57.88	75.62
9	30	30	9	1.03	203.38	57.82	**73.82**
10	10	50	5	1.21	210.63	59.24	79.23
11	30	10	9	l.11	207.65	59.19	76.04
12	50	30	5	1.08	206.78	60.57	76.22
13	50	30	1	1.12	210.77	61.40	80.07
14	10	30	9	1.18	209.65	58.53	77.83
15	30	30	5	1.09	205.10	60.39	75.19
16	30	30	5	1.10	206.09	60.11	75.23
17	50	50	1	1.08	209.23	59.35	80.14
18	30	30	5	1.10	205.10	60.50	75.19
19	30	50	9	**0.96**	**202.45**	**54.98**	74.36
20	30	30	1	1.16	208.38	61.28	78.39
21	30	30	5	1.10	205.10	60.01	75.21
22	30	10	1	1.21	212.47	61.51	80.81
23	10	10	1	1.42	216.51	62.47	83.25
24	10	30	1	1.36	213.22	62.58	81.09
25	30	50	1	1.11	207.64	59.58	78.72
26	10	50	1	1.30	213.29	61.24	81.69
27	30	30	5	1.10	205.10	60.30	75.19
28	50	50	5	1.04	205.14	57.95	76.39
29	50	10	1	1.16	215.67	61.99	82.75
30	50	10	9	1.10	209.42	60.27	76.68
31	30	30	5	1.10	205.10	60.14	75.19
32	50	30	9	1.03	204.34	58.54	74.61

The additives might have influenced the scavenging of the nitric oxide radicals leading to reduced NO_2 emission compared with the control blend. There are conflicting results of NO_x emissions from internal combustion engines with biodiesel-diesel blends. Ulusoy Y. *et al.* (2018) have stated that contradicting results are likely, depending on the experimental atmosphere and physical conditions of the test equipment, particularly the compression chamber of the engine. In their study, they had a slight decrease in NO_x emissions with increasing waste cooking oil methyl ester (WCOME) for all loads and speeds. They attributed this to a lower heat release that led to a rise in temperature due to the low caloric value of WCOME. On the other hand, Panneerselvam N. *et al.* (2016) who tested the emission characteristics of various blends of watermelon seed oil methyl ester found an increase in NO_x for B20 to B40 blends, which they ascribed to changes in the compressibility of the biodiesel leading to improved combustion and a higher temperature in the combustion chamber. Harari P. A (2017) who checked the effect of brake power on the exhaust gas of a DI (direct injection) engine run with watermelon methyl ester obtained NO_2 emission between 230ppm – 1030ppm for 1.04kW – 5.2kW brake power. Xavier J. (2020) who studied the effect of engine load on the emission of an engine run on watermelon seed oil methyl ester-diesel blends recorded 983ppm NO_x in the exhaust with B20D80 at 5kg load and it increased with the load. The combination of CuO, $CuSO_4$ and Acetoacetic ester has given a much better result though slightly higher than diesel.

The H_2S emission with the control blend was 34% lower than diesel, but the optimal additives-blend WOME11D80Ace9CuO30$CuSO_4$50 was 45% lower than diesel. Biodiesel does not contain sulphur, and with higher percentage oxygen in the additives-blend has more competitively affected the reduction reactions that should have led to increased H_2S formation, which causes corrosion and wear on the engine.

CO emitted with the control blend was 7% less than diesel but the best additives-blend WOME11D80Ace9CuO30$CuSO_4$50 achieved a 26 % reduction in CO compared with diesel. The extra oxygen molecules in the additives blend facilitated the conversion of the CO to CO_2. Asokan M.A *et al.* (2018) who worked with B20 biodiesel, which was a mixture of papaya seed oil biodiesel and watermelon seed oil biodiesel in a 1:1 ratio reported a 27.27% reduction in CO emitted compared with diesel. Other researchers working with biodiesels of diverse origin modified with nanometals had achieved a 3.4 % - 7% reduction in CO emission compared with B20D80 fuels (Karthikeyen S *et al*. 2014; Syed Aalam C *et al.* 2015; Xavier J. (2020). Apart from the work by Asokan M.A *et al.* (2018), other results we came across are inferior to ours.

The EGT with the control blend was 7.3% lower than using diesel. It was in measuring the EGT that the lowest or best value of an emission parameter was obtained outside the nineteenth experimental run, WOME11D80Ace9CuO30CuSO$_4$50. The EGT with WOME11D80Ace9CuO30CuSO$_4$50 was still 20% lower than diesel while the best additives-blend was 21% lower. The reduced EGT with the additives was probably because of smaller radiation losses, higher heat transfer coefficient, and rapid evaporation rate with improved combustion, resulting in reduced energy loss in the exhaust. Karthikeyan S. *et al*. (2014) working with ZnO B20D80 blend of promotin stearin wax obtained a 4 % reduction of the EGT compared with B20D80. Prabhu A. and Ramachandran B.A (2015) obtained a reduction of 7.67 % and 5.90 % of the EGT with Al_2O_3 and CeO_2 nanoparticles respectively as additives to pure jatropha biodiesel (B100). None of these results match our findings.

3.3 Engine performance

Tables 4 and 6 show that the additives-blend WOME11D80Ace9CuO50CuSO$_4$50, reduced the FC by 37.7% compared with the control blend, but was 11.4% higher than pure diesel. The additives had a substantial impact on the physical properties of the fuel, however, since the blends still had high viscosity and density which led to the loss of heating value, the consumption was higher than with diesel.

The BSFC additives-blend WOME11D80Ace9CuO50CuSO$_4$50 was 14.36% higher than diesel, which was a 36.64% improvement over the untreated blend. The calorific values of biodiesel blends are known to be lower than diesel with the implication of a lower evaporation rate that results in higher BSFC. The additives could not completely circumvent it. Syed Aalam C *et al.* (2015) who used aluminium oxide nanoparticles in mahua biodiesel (B20D80) in a single-cylinder four-stroke diesel engine achieved a 7.6 % reduction in BSFC. Syed Aalam C. and Saravanan C.G (2015) achieved a reduction in BSFC of 2.63 % and 5.41% with iron oxide and aluminium oxide nanoparticles respectively when dispersed in mahua biodiesel (B20D80).

Table-6: Engine performance with additives

Exp. Run	Factor 1 A:CuO (mg/kg)	Factor 2 B:$CuSO_4$ (mg/kg)	Factor 3 C:Acetoacetic ester (vol. %)	FC (l/hr)	BSFC (kg/kW.hr)	BTE(%)
1	10	10	9	1.37	1.8593	4.82
2	50	10	5	1.38	1.8711	4.92
3	30	10	5	1.39	1.8828	4.90
4	10	50	9	1.36	1.8606	4.84
5	10	30	5	1.42	1.9199	4.83
6	10	10	5	1.40	1.8937	4.89
7	50	50	9	**1.27**	**1.7423**	**5.13**
8	30	50	5	1.36	1.8437	5.00
9	30	30	9	1.33	1.8198	4.95
10	10	50	5	1.41	1.9084	4.85
11	30	10	9	1.34	1.8341	4.90
12	50	30	5	1.36	1.8435	5.00
13	50	30	1	1.40	1.8919	4.91
14	10	30	9	1.36	1.8593	4.85
15	30	30	5	1.38	1.8684	4.95
16	30	30	5	1.38	1.8680	4.95
17	50	50	1	1.35	1.8269	5.07
18	30	30	5	1.37	1.8551	4.98
19	30	50	9	1.32	1.8086	4.96
20	30	30	1	1.41	1.9025	4.90
21	30	30	5	1.38	1.8693	4.94
22	30	10	1	1.43	1.9304	4.83
23	10	10	1	1.43	1.9277	4.94
24	10	30	1	1.43	1.9270	4.86
25	30	50	1	1.41	1.9052	4.88
26	10	50	1	1.42	1.9149	4.88
27	30	30	5	1.38	1.8689	4.94
28	50	50	5	1.33	1.8058	5.08
29	50	10	1	1.43	1.9329	4.80
30	50	10	9	1.32	1.8082	4.96
31	30	30	5	1.38	1.8693	4.94
32	50	30	9	1.30	1.7812	5.04

Some other researchers who altered different B20D80 fuels with nanometals achieved a 4% to 6% reduction in BSFC (D'Silva R. *et al.* 2017; Yaliwal V. S *et al.* 2016). A much better result has been obtained here by combining acetoacetic ester with the nanoparticles of CuO and $CuSO_4$.

With the additives-blend WOME11D80Ace9CuO50CuSO$_4$50, the BTE value was 4.1% less than diesel. Imtenan S. *et al.* (2014) who modified B20D80 of palm oil and jatropha biodiesels with ethanol, n-butanol and diethyl ether achieved an increase of 3.8% - 4.4% in BTE. The combination of CuO, $CuSO_4$ and acetoacetic ester achieved a 27.9% increase in BTE over the control blend. This shows a remarkable improvement in the atomization of the fuel and the engine power due to the additives

3.4 Predictive modelling

An attempt has been made to generate a polynomial equation of the second-order that describes the engine performance and emission characteristics (equation 1)

$$Y = b_0 + b_1A + b_2B + b_3C + b_4A^2 + b_5B^2 + b_6C^2 + b_7AB + b_8AC + b_9BC \quad 1$$

Where, Y = Predicted Response (Performance and Emission Properties).
A = mass fraction of CuO.
B = mass fraction of $CuSO_4$.
C = volume of acetoacetic ester.
b_0 = intercept coefficient.
b_1, b_2 and b_3 = linear terms.
b_4, b_5 and b_6 = quadratic terms.
b_7, b_8 and b_9 = interaction terms.

When the experimental data in tables 5 and 6 were fitted to equation 1 with the design expert 11 and subjected to analysis of variance, the insignificant terms in equation 1 with Prob.>F>0.05 were truncated leading to equations 2 to 8. The reliability of the equations has been tested with the experimental data as shown in figs 2a, 2b, 2c and 2d, and figs 3a, 3b and 3c.

$$H_2S_{calculated} = 1.63026 - 0.018551\,A - 3.35674 \times 10^{-3}B - 0.016501C + 1.94892 \times 10^{-4}A^2 - 4.40188 \times 10^{-4}C^2 + 1.875 \times 10^{-5}\,AB + 2.8125 \times 10^{-4}\,AC - 1.35417 \times 10^{-4}BC \quad 2$$

$$NO_{2calculated} = 224.40029 - 0.52119\,A - 0.29765B - 0.80552C + 8.88306 \times 10^{-3}A^2 + 4.02473 \times 10^{-3}B^2 + 0.043222C^2 - 2.17917 \times 10^{-3}\,AB - 8.25 \times 10^{-3}\,AC \quad 3$$

$$CO_{calculated} = 62.69907 - 0.10558A + 0.094691B + 0.064542C + 1.62419 \times 10^{-3}A^2 - 1.84664 \times 10^{-3}B^2 - 0.039916C^2 - 8.58333 \times 10^{-4}AB + 3.79167 \times 10^{-3}AC - 7.07292 \times 10^{-3}BC \quad 4$$

$$EGT_{calculated} = 88.82952 - 0.32439\,A - 0.22668B - 0.927C + 5.49341 \times 10^{-3}A^2 + 3.28091 \times 10^{-3}B^2 + 0.057752C^2 - 7.5 \times 10^{-4}\,AB - 8.1875 \times 10^{-3}\,AC \quad 5$$

$$FC_{calculated} = 1.43360 + 1.12007 \times 10^{-4}A + 4.90479 \times 10^{-4}B - 2.64673 \times 10^{-3}C - 5.44355 \times 10^{-5}C^2 - 3.54167 \times 10^{-5}AB - 1.04167 \times 10^{-4}AC \quad 6$$

$$BSFC_{calculated} = 1.93756 + 6.025 \times 10^{-4}A + 3.22326 \times 10^{-4}B - 8.55104 \times 10^{-3}\,C - 5.00833 \times 10^{-5}\,AB - 1.35 \times 10^{-4}AC \quad 7$$

$$BTE_{calculated} = 4.95194 - 3.76389 \times 10^{-3}\,A - 2.17014 \times 10^{-3}B - 0.01066\,C + 1.41667 \times 10^{-4}AB + 5.41667 \times 10^{-4}AC \quad 8$$

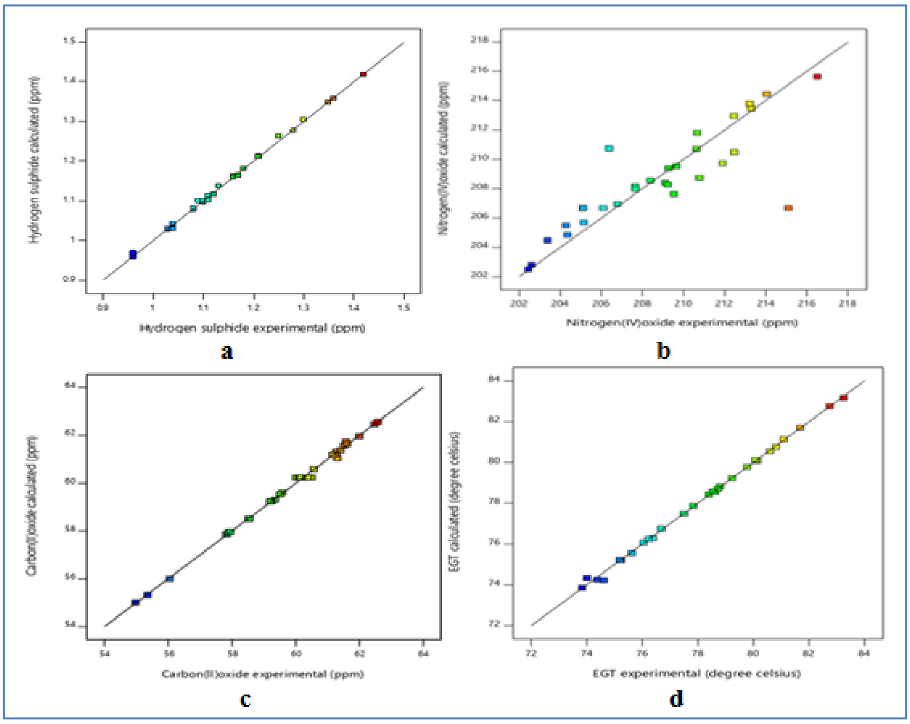

Fig-2: Diagonal plots of the emission properties (a) hydrogen sulphide (b) nitrogen (IV) oxide, (c) carbon (II) oxide, (d) EGT.

Figures 2 a,b,c and d have adjusted correlation coefficients (R^2) of 0.9973, 0.7953, 0.9963 and 0.9981 respectively. Based on the values of adjusted R^2, the equations for predicting the emission of H_2S, CO and EGT are reliable.

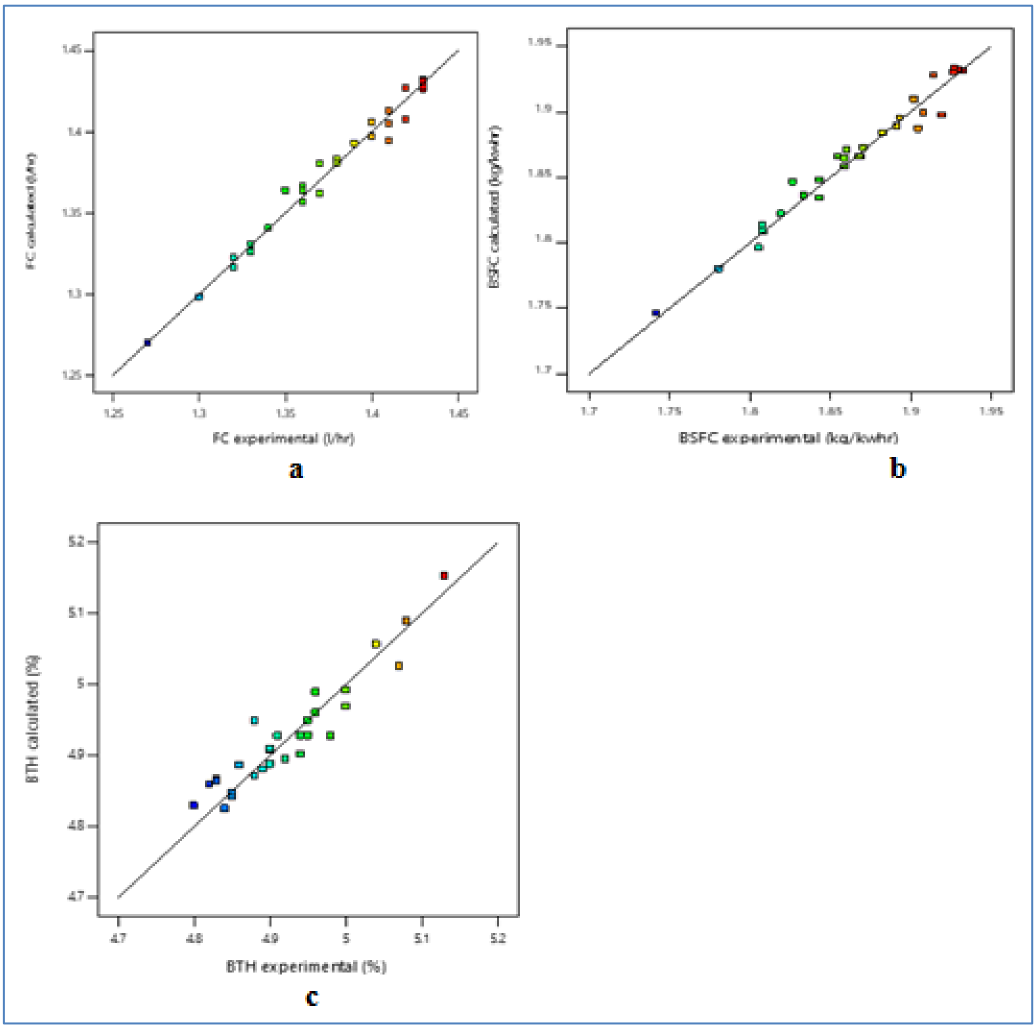

Fig-3: Diagonal plots of the performance properties (a) FC, (b) BSFC, (c) BTE

The adjusted R^2 of figures 3 a, b and c are 0.8918, 0.8615 and 0.8585 respectively. The equations for predicting FC, BSFC and BTE are fairly good and may provide a guide on the engine performance in the absence of experimental data. However, the equations for estimating H_2S, CO and EGT are better predictive tools.

4.0 CONCLUSION

The additives acetoacetic ester, CuO and $CuSO_4$ nanoparticles improved substantially the emission (H_2S, NO_2, CO, EGT) and performance (FC, BSFC, BTE) properties of WOME20D80 in the four-cylinder four strokes CI engine. Compared with pure diesel, the emission properties were all improved except NO_2 which was higher by 6.3 %. Though the performance properties improved between 27.9 % - 37.7 % over WOME20D80, none of the values matched what was obtained with diesel. That notwithstanding, the additives gave emission and performance characteristics better than most of what had been reported in the literature using other additives, including in some cases CuO and $CuSO_4$. The third additive acetoacetic ester provided more oxygen to ease combustion, but would lead to a slight increase in the operational cost, which should be offset by its overall impact on the combustion properties of the fuel. Equations have been presented that can serve as a guide to predict the emission and performance properties of a CI engine that is run on WOME20D80 with the additives.

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