The Effect of Variable Engine Parameters on Performance and Emissions of DI Diesel Engine Running on DieselBiodiesel Blended with Nano Additive

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Abstract:

The influence of changing engine parameters like injection time and compression ratio on performance and emission characteristics of single cylinder four stroke Ricardo E6/US diesel engine operating on biodiesel blends with nano additive was studied experimentally. Transesterification created biodiesel from leftover cooking oil. In the mixture, there were varied weight fractions of iron oxide nanoparticles (Fe2O3) (B5, B10, B15, and B20) and diesel fuel (B5, B10, B15, and B20) (vol%). It was injected at (20, 30, 38, and 40) bTDC, with a compression ratio of (16:1, 17:1, 18:1 and 20:1). The Taguchi method's design of experiments technique was used to determine the best biodiesel mix (B20), nano additive (100ppm), injection time (38 bTDC), and compression ratio for engine performance (17). The findings revealed that adding nano additive to biofuel boosted BTE by 15.05 percent and lowered BSFC by 10.73 percent. Comparatively, CO, HC and smoke density decreased by 62.5, 63.1 and 28.9 percent, although NOx and PM rose by 16.19 and 15.30 percent.

Keywords Diesel engine, Injection timing, Performance, Emissions, Diesel fuel, Waste cooking oil, Iron oxide Nanoparticle, Taguchi method

1. Introduction:

Complying with possible pollution limits while enhancing performance and fuel efficiency is a key goal for compression ignition engine development.

Current and developing after-treatment technologies show promise, but their high cost and complexity threaten the diesel engine package's viability. However, recent research on diesel homogenous charge combustion has shown an alternate technique to improve performance while lowering NOx and PM emissions [1-3]. Diesel fuel is one of the key sectors for researchers to examine improving fuel qualities.

The researchers are interested in low-emission fuels that are produced worldwide for industrial growth. Compression ignition engines using hydrocarbon fuel produce large amounts of NOx and PM [4].

One approach to do this is to use alternative fuels instead of petroleum. Alternative fuels are renewable and green. One downside of alternative fuel is that it has a lower heating value than diesel. Blending may have a big impact on the combustion properties. Because the molecular structure of these two fuels differs, using biofuel in a diesel engine reduces efficiency compared to using diesel oil [5]. Karthik et al. [6] investigated the effects of blending biodiesel (RSO20) with diesel oil on a single-cylinder compression ignition four-stroke air-cooled engine with constant speed and variable injection timing. As injection time advances, the findings reveal that (RSO20) brake thermal efficiency increases at 30° bTDC, while brake fuel consumption decreases. Mehta and Shrivastava [7] studied the impact of variable injection time on performance and emission characteristics of a single cylinder four-stroke diesel engine running on diesel and soybean oil biodiesel. We tested 23°, 26°, and 29° bTDC injection

timings for biodiesel blends using Diesel-RK Simulation software. The findings indicated that although engine performance improved, particulate matter and smoke opacity emissions rose with injection time.

Adding nanoparticles to biodiesel improves its properties. Increased fuel calorific value improves engine efficiency owing to metal oxide particle efficacy [8].

Nano additives offer superior thermal and physical properties compared to basic fuels, such as increased contact surface area and surface area to volume ratio in the fast oxidation process [9]. They investigated the impact of nanofuel on the physicochemical parameters, performance, and emissions of a four-stroke, water cooled, compression ignition engine. Jatropha oil biodiesel. The fuel additive utilised was cerium oxide (10-20nm) with 7.13 g/mL density. The use of nanoparticles raised the flashpoint and viscosity of biodiesel. The inclusion of nanoparticles reduced HC and NOx emissions. They examined the impact of nano-added magnalium oxide (Al-Mg) and cobalt oxide (CO3O4) on a single-cylinder, four-stroke, air-cooled, direct injection diesel engine operating on mixed dieseljatropha oil. The addition of nanoparticles to biodiesel reduces HC and CO at full load and 75% load. Also, NOx levels were greater in tidy biodiesel operations.

For their study, Manibharath et al. [12] used a single-cylinder, four-stroke, air-cooled, direct injection diesel engine using nano additives. Nanoparticles were (100nm). The inclusion of nanoparticles reduces specific fuel consumption at half load and full load. It also decreases CO_2 buildup. According to Patel and Kumar [13], using bio-diesel decreases emissions from diesel engines, reducing pollution, but it also affects engine performance. Furthermore, adding nano aluminium oxide (n-Al_2O_3) to diesel enhances performance and reduces emissions. Narendrasai et al. [14] examined the performance and emissions of algal bio-diesel engines. The test used a single cylinder four stroke naturally aspirated open chamber (direct injection) water-cooled diesel engine running at constant speed (1500 rpm). Transesterified algal oil was used to make biodiesel, which was then combined with diesel. Also, cerium oxide was added.

With nano additives (B20), the best thermal efficiency is achieved with the least fuel consumption and the least NOx/HC/CO_2 emissions at full load. Adzmi et al. [15] investigated the effects of a nano additive containing palm oil methyl ester (POME) on the performance and emissions of a single-cylinder watercooled direct injection diesel engine (YANMAR TF120M) under varied loads. The nanoparticles of aluminium oxide and silicon dioxide were mixed (POME). Brake specific fuel consumption was lowered by 15% using biodiesel-nano additive mixes. Compared to plain biodiesel, it emits less CO, CO_2, and NOx. Many scholars employed Taguchi experimental design to analyse engine design parameters [16-18].

The Taguchi approach is a straightforward, effective, and efficient way to build a decent engine [16]. The performance and emission characteristics of diesel and biodiesel engines with varied percentages of iron oxide (Fe_2O_3) nanoparticles are anticipated in this paper. The ideal performance characteristics of DI diesel engines are determined for testing using the Taguchi technique of experimental design.

2. Materials and methods

2.1. Biodiesel Production

Transesterification turns fats into biodiesel (methyl ester fatty acid and glycerol). In this investigation, one litre of WCO was mixed with 200 ml methanol (6:1) and 1.5 g potassium hydroxide (KOH) at 60°C. To remove contaminants and glycerol, the methyl ester was separated from glycerol and washed many times with distilled water, before being boiled to remove excess water and methanol.

It was then dried using sodium sulphate (Na_2SO_4). This was followed by filtering using qualitative filter paper. The end result was dark yellow. Figure 1 depicts the biodiesel manufacturing process (1). Biodiesel was blended with diesel oil in various quantities (B5, B10, B15, and B20).

Figure 1. Process of biodiesel production

2.2. Nano metal additive

Many researchers advocate the approach of improving fuel by adding nanoparticles. Nano additives were employed to improve the performance of the C. I. engine and to reduce emissions. This has improved their thermal conductivity, evaporation rate, reduction in delay time, and surface area while promoting secondary atomization [13,14]. Iron oxide nanoparticle (Fe2O3), purity 99 percent, particle size 20-30nm, acquired from a special agent for chemicals in Baghdad. Alsalam Nanotechnology and Advanced Material Research Center Yniversity of TechnologyBaghdad/Iraq tested it. Table 1 lists the properties of nanoparticles (Fe2O3).

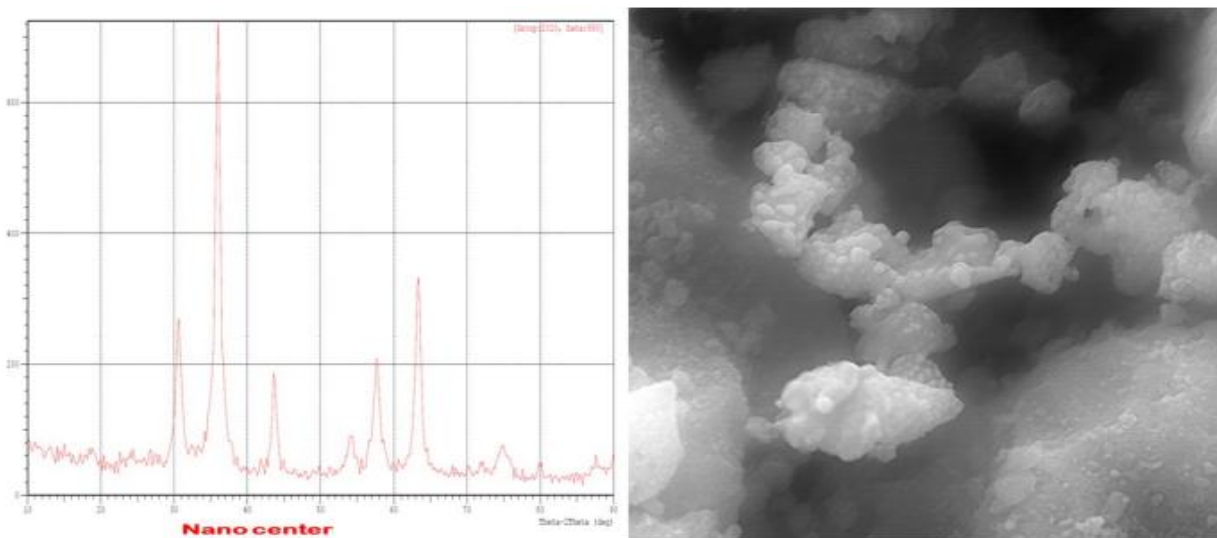Figure 2. XRD and SEM images of nanoparticles Fe2O3.

Table 1. The specification of nanoparticles-Fe_2O_3.

Item	Nano-Fe_2O_3 specifications
Manufacturer	Nanjing Nano. Alpha-China
Appearance	Red brown powder
Assay	99%
Structure	Spherical
Crystal and Type	α-Fe_2O_3
Grain size nm e	20–30 nm
pH value	5-7
Specific Surface area (m^2/g)	40-60
Bulk density	1.20 g/cm^3
True Density	5.24 g/cm^3

2.3. Nano-diesel-biodiesel fuel preparation

A transesterification technique was used to produce biodiesel from waste cooking oil acquired from Baghdad-based Dura-Refinery. Also, iron oxide nanoparticles (Fe2O3) were purchased from a Baghdad source. Using an ultrasonic shaker, nano fuel was made by combining diesel-biodiesel with nanoparticle (Fe2O3) at varying percentages (10ppm, 30ppm, 50ppm, 70ppm, and 100ppm). Because nanoparticles have a larger surface area, their surface power is strong, causing them to clump together and form a micro molecule. An ultrasonic device was utilised to avoid this flaw. To produce homogenous nano fuel, one sample is mixed in an ultrasonic device for two hours. Figure 3 and table 2 illustrate the processing and physical parameters of diesel fuel with nano additions.
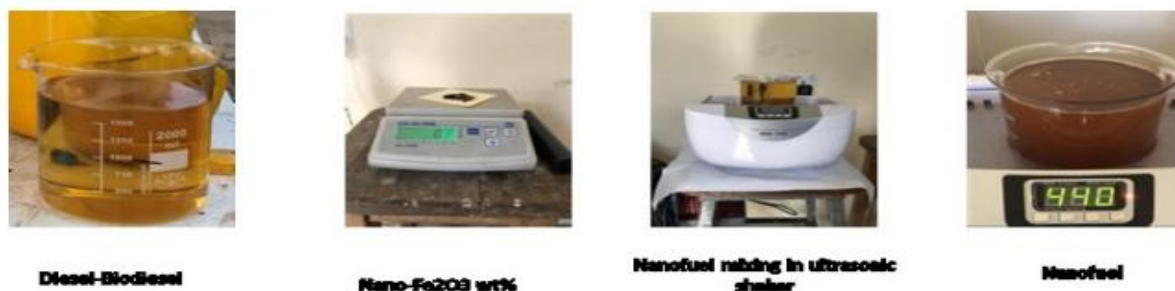

Diesel-Biodiesel   Nano-Fe2O3 wt%   Nanofuel mixing in ultrasonic shaker   Nanofuel

Figure.3. Nano fuel prepared method

Table 2. Physical characteristics of diesel, biodiesel, nano fuel.

Fuel Sample	Diesel (vol%)	Biodiesel (vol%)	Nano-Fe2O3 (wt%)	KV@38 °C Cst	Density(kg/m3) @38°C	CN	LCV (kj/kg)	Flash point (°C)	Fire point (°C)
D100	100	-------	-------	2.72	830	52	42,500	67	86
B100	----	100	-----	5.56	890	56	37000	102	126
D80:B5	95	5	------	2.86	832.4	52.4	42,225	68.8	88
D80:B10	90	10	------	3.0	834.8	52.6	41,950	69.5	90
D80:B15	85	15	------	3.15	837.2	53.1	41,675	70.4	91.4
D80:B20	80	20	------	3.3	838.5	53.4	41,400	71.5	92
D80:B20:10ppm	80	20	10ppm	3.33	840.3	53.5	41,414	71.9	92.7
D80:B2:30ppm	80	20	30ppm	3.35	841.7	53.6	41,521	72.3	93.1
D80:B20:50ppm	80	20	50ppm	3.37	843.3	53.7	41,607	72.7	93.5
D80:B20:70ppm	80	20	70ppm	3.39	845.1	53.8	41,690	73.1	93.7
D80:B20:100ppm	80	20	100ppm	3.51	847.5	53.9	41,814	73.5	94

3. Test engine and examination devices

The work used a single-cylinder four-stroke diesel engine (Ricardo E6/US). Table 3 lists the engine specifications utilised in the study. The engine is connected to a DC dynamometer for independent setting of speed and power. bTDC injection time, whereas compression ratio for (16:1, 17:1, 18:1 and 20:1). It was measured using a K-type thermocouple and a GEMO-DT109A digital reader. The AEA-CG450 analyzer measured CO, HC, NOx, CO2, and O2. AVL-491 smoke metre, AEROCET-531S. Figures 4 and 5 show the test setup arrangement and a shot of the engine and its attachments.

Table 3. The details of the engine specification.

Engine Model	Ricardo E6/US
Engine Type	Single Cylinder four Stroke Direct Injection Diesel Engine
Swept Volume	507 cc
Bore	76.2 mm
Stroke	111.1 mm
Compression Ratio	4.5-22 (Variable)
Rated Brake Power	9 kW, Natural Aspirated
Rated Speed	1800 rpm
Cooling System	Water Cooled
Nozzle Opening Pressure	150 bar
Injection Timing	(20-45 °) (Variable)

1. Engine test
2. Dynamometer
3. Tachometer
4. Oil pump
5. Flyweel
6. Torque gauge
7. Fuel pump
8. Fuel consumption gauge
9. Fuel tank
10. Airbox tank
11. Orifice airflow
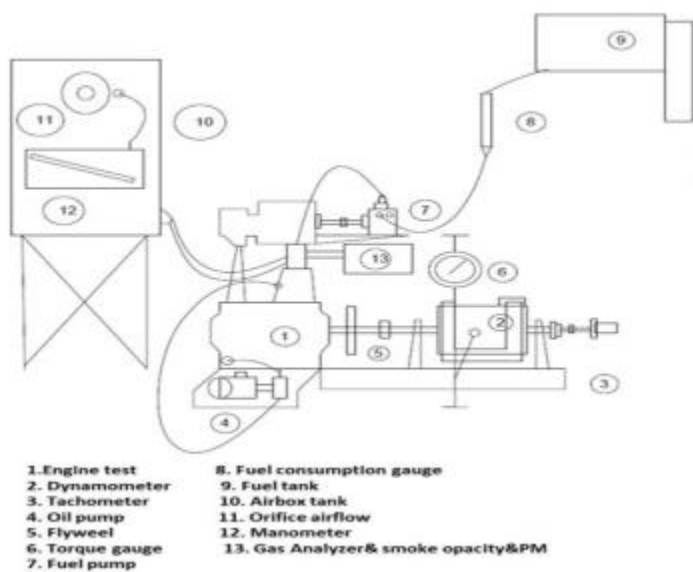12. Manometer
13. Gas Analyzer& smoke opacity&PM

Figure 4. Schematic diagram of test engine setup

Figure 5. Ricardo engine and its accessories

4. Taguchi method of optimization (DOE)

The Taguchi technique is a collection of numerical and statistical methods used for parametric optimization and abstract problem solving. The Taguchi approach finds the association between a response and a set of experimental lowest and maximum values.

This approach relies on a "Orthogonal Array". Orthogonal arrays enable examine a large number of variables with few trials. The new study uses four variables at four levels, hence the practical arrangement uses an L16 orthogonal array. Table 4 shows the injection time, compression ratio, biodiesel mix, and nano additive proportion for the L16. Using this method, sixteen (16) tests were run, with trials chosen at random to avoid systematic error. In each trial, the response variable was the brake thermal efficiency and specific gasoline consumption. S/N is a helpful measure for assessing quality. Figures 6 and 7 demonstrate the optimal S/N ratio used in this practical investigation. Table 5 shows the results of assessing engine performance.

Table 4. Practical variables and their levels.

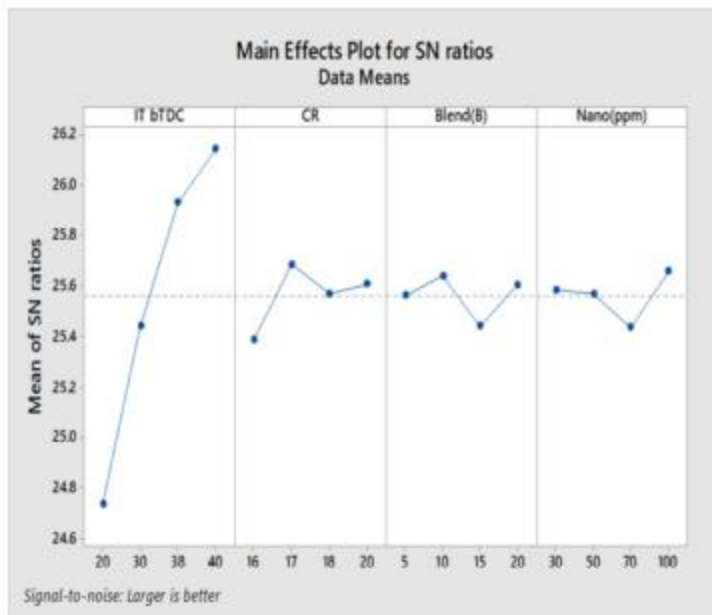| Parameters	L 1	L 2	L 3	L 4
IT (bTDC)	20	30	38	40
CR:1	16	17	18	20
Blend(B%)	5	10	15	20
Nano (ppm)	30	50	70	100

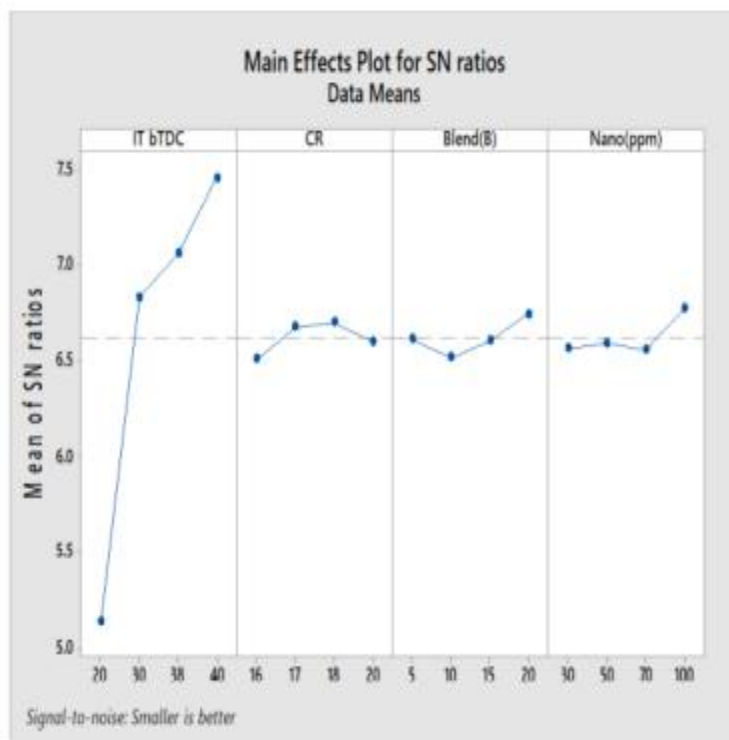Figure 6. Response diagram of S/N ratio for BTE.

Figure 7. Response diagram of S/N ratio for BSFC.

Table 5. Optimum parameter settings for engine performance.

IT (bTDC)	CR	Blend (B)	Nanoparticles (ppm)
38	17	B20	100

5.   Results and discussion:

The experiment investigated the effects of injection time and compression ratio on performance and emissions of biodiesel combined with diesel oil and nano additives. Biodiesel blend percentages (B5, B10, B15, and B20) vol% and nanoparticle additive concentrations (10ppm, 30ppm, 50ppm, 70ppm, and 100ppm) wt% were used. We used Taguchi Optimization to choose the best engine settings (injection timing, nano additives, biodiesel mixes, and compression ratio).The findings were obtained with a constant engine speed (1800 rpm) and various loads (3.2 Nm, 6.86 Nm, 9.14 Nm, 12.34 Nm, 16.45 Nm, and 20.56 Nm). All performance statistics were plotted versus braking power (BP).

5.1. Performance characteristics

5.1.1. Brake thermal efficiency (BTE)

Figure 8 demonstrates the fluctuation of BTE with braking power for pure diesel DF, biodiesel DF+BIO, and biodiesel with nanoparticles DF+BIO+NANO mixed. The findings demonstrate that DF+BIO and DF+BIO+NANO improve the engine's thermal efficiency by 12.75 and 15.05 percent, respectively. The inclusion of nanoparticles to bio-diesel blends improves fuel characteristics by regularising combustion processes.
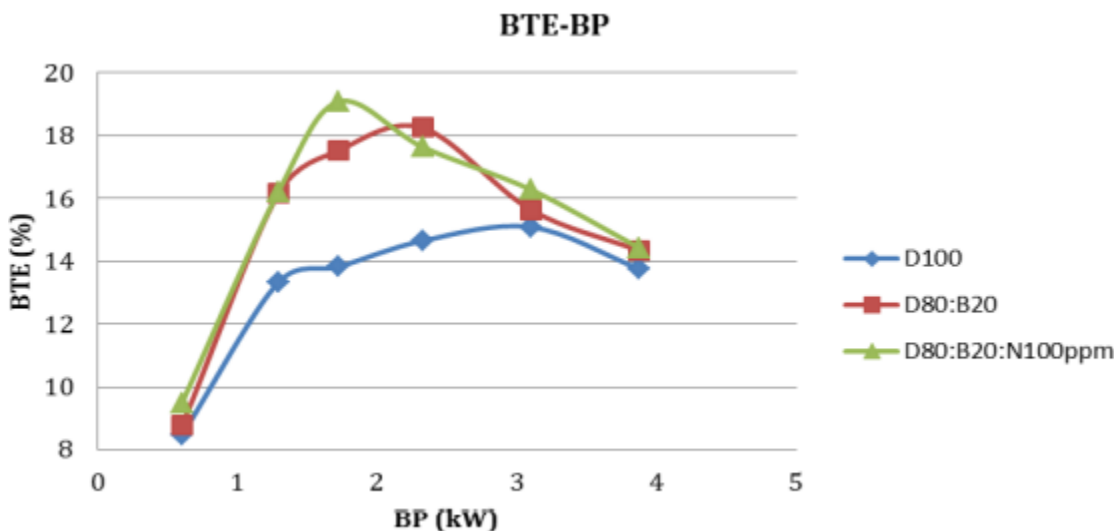

Figure 8. Variation of brake thermal efficiency v/s brake power

5.1.2.   Brake specific fuel consumption (BSFC)

Figure 9 demonstrates the fluctuation of brake specific fuel consumption (BSFC) with braking power (BP) for pure diesel DF, biodiesel mixed diesel DF+BIO, and nanoparticles blended diesel DF+BIO+NANO. The BSFC is reduced by 8.10% and 10.73% for DF+BIO and DF+BIO+NANO mixed fuels, respectively. Compared to diesel, the greater calorific value of the fuel increases the combustion process owing to the presence of nanoparticles.
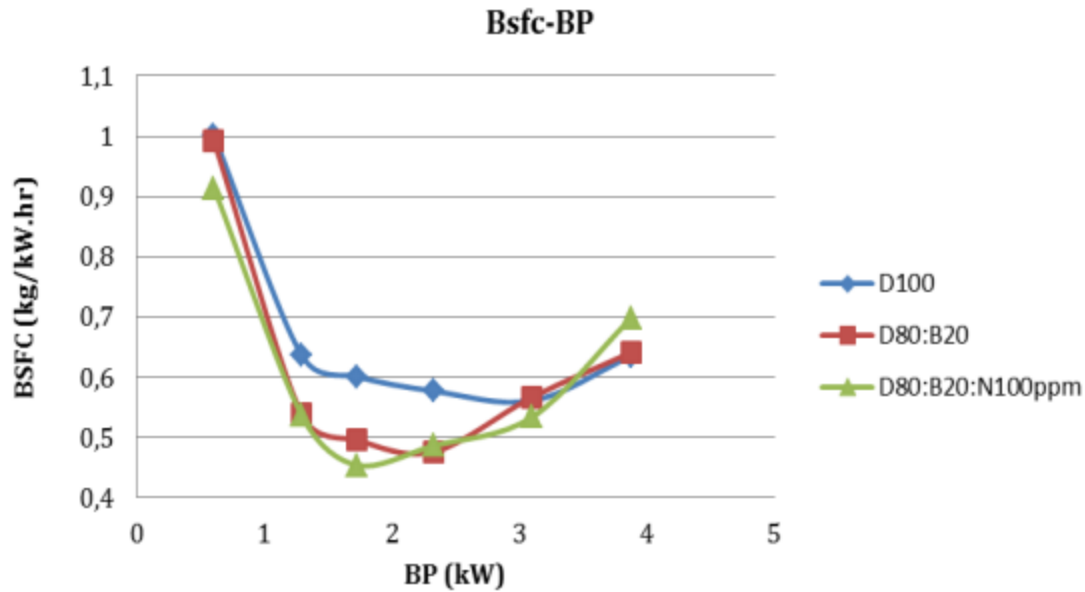
Figure 9. Variation brake consumption fuel v/s brake power.

6. Conclusions

On a four-stroke Ricardo E6/US single cylinder diesel engine with nanoparticle additive, the influence of various engine parameters on performance and exhaust emissions was studied (Fe2O3). This research came to the following conclusions:

1. Adding iron oxide nanoparticles to biofuel improves thermal efficiency and reduces brake fuel consumption by 15% and 10%, respectively, compared to diesel fuel.

2.A single cylinder four stroke Ricardo E6/US diesel engine was used to investigate the effects of various engine settings on performance and exhaust emissions while using diesel and waste cooking oil (biodiesel) with nanoparticle additive (Fe2O3).

This research came to the following conclusions:

Adding iron oxide nanoparticles to biofuel improves thermal efficiency and reduces brake fuel consumption by 15% and 10%, respectively, compared to diesel fuel.

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