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## **INFLUENCE OF ACETONE AS OXYGENATOR ADDITIVE ON THE COMBUSTION, PERFORMANCE, AND EMISSION OF DIESEL-BIODIESEL BLENDS IN DIRECT INJECTION DIESEL ENGINE**

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### **ABSTRACT**

Diesel fuel additives are chemicals which are added to the vehicles fuel to improve engine performance, combustion properties, and emission characteristics. In this paper, the experimental investigations of the effect of diesel-biodiesel-acetone emulsion fuels on the performance and emissions of a direct injection diesel engine have been reported. The tests were conducted on one-cylinder naturally aspirated compression ignition engine operated at 1600 rpm. Measured characteristics were torque, power, brake thermal efficiency, specific fuel consumption, exhaust gas temperature, and exhaust gases of CO, CO<sub>2</sub>, unburned hydrocarbons (UHC), NO, and O<sub>2</sub>. The obtained results show that the torque, power, and Break Thermal Energy were increased when we compare the engine operation with pure diesel fuel. Additionally, the specific fuel consumption and engine exhaust gas temperature were reduced. The CO, UHC, and soot emissions were decreased. However, the NO emission was increased.

### **KEYWORDS**

Oxygenator Additive, Biodiesel/ Diesel Blends, Engine Emission, DI Diesel Engine

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## NOMENCLATURE

### Abbreviations

ASTM	American Society for Testing and Materials	BSFC	Break Specific Fuel Consumption
B0	Pure diesel	BSEC	Break Specific Energy Consumption
B100	Pure biodiesel	BTE	Brake Thermal Efficiency
B10	90% Diesel + 10% Biodiesel	WCO	Waste Cooking Oil
B20	80% Diesel + 20% Biodiesel	HHV	Higher Heating Values
B30	70% Diesel + 30% Biodiesel	ppm	part per million
B40	60% Diesel + 40% Biodiesel	rpm	revolutions per minute
B50	50% Diesel + 50% Biodiesel	DI	Direct Injection
B20AC2	80% Diesel + 20% Biodiesel+2% Acetone	CO <sub>2</sub>	Carbon Dioxide
B20AC4	80% Diesel + 20% Biodiesel+4% Acetone	NO <sub>x</sub>	Nitrogen Oxides
B20AC6	80% Diesel + 20% Biodiesel+6% Acetone	HC	Unburned Hydrocarbons
B50AC2	50% Diesel + 50% Biodiesel+2% Acetone	CO	Carbon Monoxide
B50AC4	50% Diesel + 50% Biodiesel+4% Acetone	O <sub>2</sub>	Oxygen
B50AC6	50% Diesel + 50% Biodiesel+6% Acetone		

## INTRODUCTION

Diesel engines are used widely in power generation, agriculture field and sectors of transportation due their better efficiency, low fuel consumption, safety and durability over gasoline engines [1]. However, diesel engines are noticed as high emission contributor to the environment, which is hazardous to human health [2]. So, we should follow these regulations to control the emission levels from diesel engines. Improvement in the performance of diesel engines is an important challenge to be addressed in the current era due to the fast depletion of fossil fuel resources as well as due to the harmful hydrocarbon and nitrogen oxides emissions [3, 4]. Efforts are also made for their formulation of diesel fuel to reduce these harmful emissions without affecting the physicochemical properties of fuel such as viscosity, flash and fire point [5].

In recent times researchers have focused more on alternate fuels, with the depleting trend of petro diesel [6-8]. Also the stringent regulations on emission of diesel engine promote the use of alternative fuels and emission reduction technology. A treatment technology will help to reduce particulate emission and NO<sub>x</sub> emission in diesel engines, but with a fuel consumption penalty. One way to save diesel fuel is to improve CI engine performance and emission or use of alternative fuels prepared from non-edible oil seeds. Keeping in view the need to reduce consumption of petroleum products and simultaneously implement stringent engine emission norms all over the country. Sunflower, safflower, soybean, cotton, winter rape, canola, and peanut are the most predominant oil bearing crops considered as fuel substitutes [9].

Biodiesel is one of alternate fuels with calorific value close to diesel [10]. Most researchers concluded that with the usage of biodiesels, emissions can be reduced while maintaining efficiency, compared to diesel [5]. Global warming can be reduced by blending biodiesel fuel with diesel hence the combustion of biodiesel does not increase the global balance of CO<sub>2</sub> [11, 12]. Several experimental investigations have been carried out around the world to evaluate the CI engine performance of different biodiesel blends. Researchers reported that the use of biodiesel and its blends in CI engine results in loss of torque, power, and also increase in BSFC [12].

Researchers have conducted experiments to improve the properties of blends of biodiesels and petroleum diesel. Numerous experiments were performed in which researchers blended a single biodiesel with petroleum diesel [13-21]. Optimized multiple biodiesel blends have also been created [22]. However, the use of additive is another convenient way to improve emission and performance of biodiesel–diesel blend [23]. Current studies have shown that ethanol, n-butanol, and diethyl ether are among the biofuels that have the highest potential to function as fossil fuel supplements and can be easily used as additives [24]. Experiments show that the fuel properties of ethanol–biodiesel–diesel blends are almost similar to those of diesel [23].

N-butanol is a strong competitor of ethanol and has less hydrophilic tendency, higher miscibility, higher Cetane number, and higher calorific value [25, 26]. Diethyl ether also has some favorable characteristics such as high Cetane number, low autoignition temperature, reasonable energy density, high miscibility, and broad flammability range [24]. It can be produced from ethanol via a dehydrating process. Rakopoulos [24] reported improved emissions and performance when n-butanol and diethyl ether were used with cottonseed biodiesel. Altun et al. [27] also reported improvement of cottonseed biodiesel–diesel blend with n-butanol as additive. Qi et al. [23] found that the performance and emission characteristics of biodiesel–diesel blend improved with the addition of diethyl ether and ethanol. Mallikarjun et al. [28] experimented with Mahua methyl ester and diethyl ether blend with diesel fuel. They reported, BTE increased as diethyl ether was introduced. CO and smoke increased with the increased portion of diethyl ether but NO<sub>x</sub> decreased remarkably. Other researchers have cited various biodiesel–diesel blend improvements in terms of performance and emissions characteristics with the addition of the same oxygenated additives [29-31].

The main focusing of the present paper is to improve the emissions and performance characteristics of diesel-biodiesel blends with the combinations of acetone fuel additives. This additive working though increases the fuel-bound oxygen, which can produce better combustion and improve (reduce) density of the blend, thereby maintaining viscosity within an acceptable range. The introduced blends consisted of diesel, biodiesel, and acetone. Performance improvement will be analyzed in the context of brake thermal efficiency (BTE). Combustion analysis of the fuels has done to go deeper into the performance and emission which including NO<sub>x</sub>, CO, CO<sub>2</sub>, O<sub>2</sub> and HC.

## **EXPERIMENTAL SETUP**

### **Equipment and Set Up**

#### **Test engine**

The diesel engine with model S1100A2 is tested at ambient temperature of 24°C and atmospheric pressure of 101 kPa. The engine specifications are shown in Table 1.

#### **Hydraulic Dynamometer**

In order to measure the engine load and torque, a hydraulic dynamometer is used, model ATE-160 LC, its specifications are shown in Table 2.

**Table 1.** Specifications of the used diesel engine.

Model	S1100A2
Type	single-cylinder, four-stroke, horizontal, and swirl combustion chamber
No. of cylinder	1
Bore	100 mm
Stroke	115 mm
Displacement	0.903 L
Compression ratio	20
Power	11KW/2200 r.p.m.
Type of cooling	water-evaporative
Net weight	155 kg

**Table 2.** Specifications of the used Hydraulic Dynamometer.

Dynamometer Model	ATE-160 LC
Type of Weighing Mechanism	Load Cell with Digital Torque Indicator
Capacity Of Load Cell	0 to 350 Kg. (0 to 1050 N-m)
Calibration Lever Arm Length	0.7645 meter
Speed Sensing	60 Tooth Wheel and Sensor
Drive Attachment	Half Coupling Attached to Shaft
Type Of Absorption	Water/Hydraulic

### Emission Analyzer

The HPC500/400 Automotive emission analyzer is used (Fig. 1). It has the extensive options for emission diagnostics (such as HC, CO, CO<sub>2</sub>, O<sub>2</sub>, and NO). The accuracy of all measurements and the uncertainties in the calculated results are presented in Table 3.



**Fig. 1.** Emission Analyzer.

### Fuel Preparation

The employed diesel fuel was obtained locally from commercial petroleum reserve. The WCO biodiesel is prepared by a chemical process named transesterification that follows the optimized transesterification methodology as suggested by Ultu and Kocak [32], 1 Liter of WCO needs 8 g of NaOH and 240 g of methanol. The mixture is stirred and maintained at 65 °C for 1 hour then it is allowed to settle down under its

**Table 3.** The accuracies of the measurements and the uncertainties in the calculated results.

Parameters	Measurement range	Accuracy	Uncertainties (%)
Speed	0–8000 rpm	±5 rpm	±0.06
Torque	0–110 Nm	±0.05 Nm	±0.05
Power	0–92 kW	±0.07 kW	±0.08
Flow rate	0.1–30 l/h	±0.02 l/h	±0.06
SFC	–	–	±0.4
LHV	–	–	±0.1
BTE	–	–	±0.2
Kinematic Viscosity	0.2–20000 mm <sup>2</sup> /s	–	±0.1
Dynamic Viscosity	0.2–20000 m Pa.s	–	±0.1
Density	0.65–3.0 g/cm <sup>3</sup>	0.0001 g/cm <sup>3</sup>	±0.003
Humidity	3–99%	±0.5%	±0.5
Temperatures	0–1000 °C	±1 °C	±0.1
Ambient pressure	700–1100 mbar	±1 mbar	±0.09
CO	0–15.0 vol.%	±0.01 vol.%	±0.07
CO <sub>2</sub>	0–20.0 vol.%	±0.01 vol.%	±0.05
O <sub>2</sub>	0–25.0 vol.%	±0.01 vol.%	±0.04
HC	0–30000 ppm vol.	±1 ppm vol.	±0.003
NO	0–1000 ppm vol.	±1 ppm vol.	±0.1

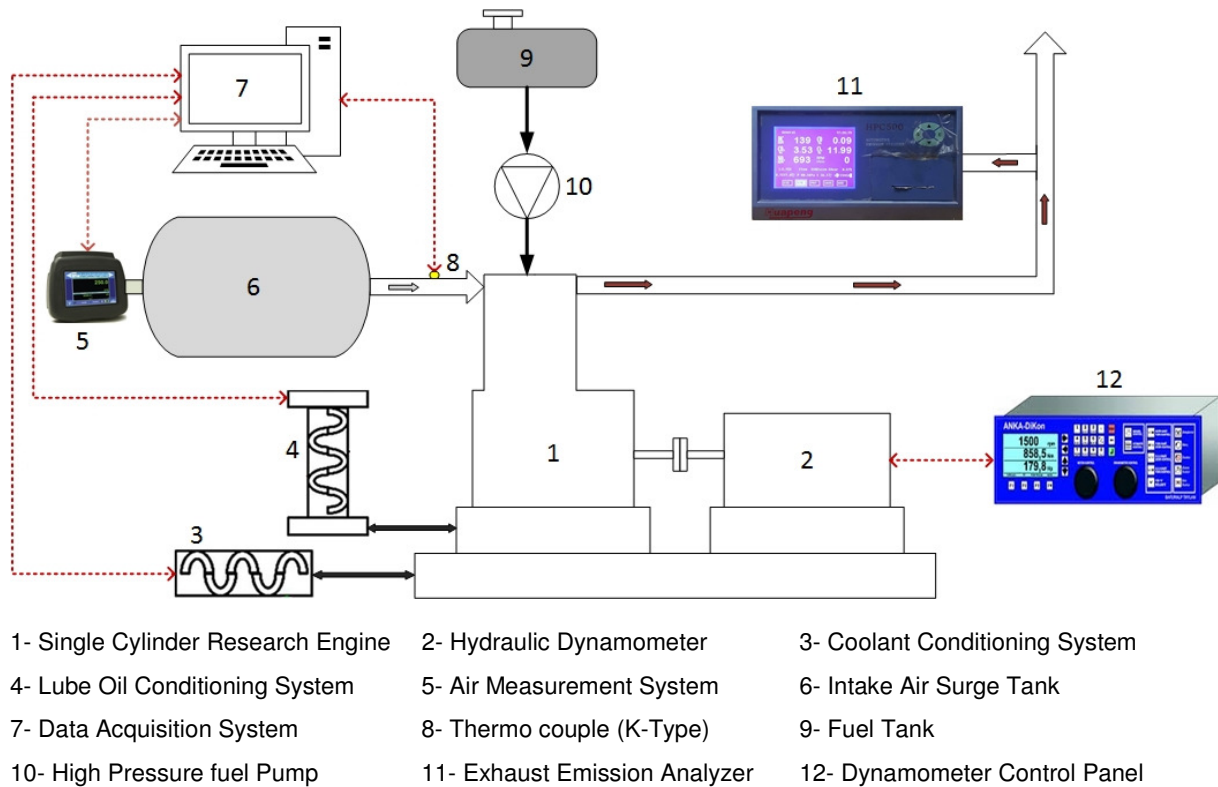
gravity. This led to the mixture separation for two layers; raw biodiesel forms the upper layer and glycerin at the lower one. The separated raw biodiesel is washed twice by using the same volume of hot water and is allowed to settle down under gravity for 24 hours. After separation the water forms the lower layer and can be separated. Moisture is removed from this raw biodiesel by evaporation with heating process, and the pure biodiesel is ready. So, diesel-biodiesel blends B10, B20, B30, B40 and B50 can be prepared by mixing diesel with the biodiesel by the required ratios. Then acetone was added as an oxygenated additive with concentrations of 2%, 4%, and 6% to B20 and B50 blends. Table 4 shows some specifications of the fuels.

**Table 4.** Some fuels specifications measured based on ASTM standard.

Fuel	Density (gm/cm <sup>3</sup> )	Kinematic Viscosity (mm <sup>2</sup> /s)	Dynamic Viscosity (mPa.s)	HHV (MJ/kg)	LHV (MJ/kg)
B0	0.8201	2.2732	1.8642	45.699	42.858
AC	0.7803	3.57	2.7857	31.862	29.589
B100	0.85	4.76	4.046	41.14	39.688
B10	0.823	2.4475	2.0145	45.243	42.541
B20	0.826	2.6353	2.1769	44.787	42.224
B30	0.829	2.8374	2.3524	44.331	41.907
B40	0.832	3.055	2.5420	43.875	41.59
B50	0.835	3.2894	2.7468	43.419	41.273
B20AC2	0.8249	2.6396	2.1776	37.521	35.203
B20AC4	0.8238	2.6439	2.1783	44.324	41.756
B20AC6	0.8227	2.6482	2.1789	44.093	41.522
B50AC2	0.8339	3.2948	2.7477	43.188	41.039
B50AC4	0.8328	3.3002	2.7486	42.957	40.805
B50AC6	0.8317	3.3056	2.7495	42.726	40.571

## Experimental Procedure

In present work, the fuel blends with specifications of B0, B100, B10, B20, B30, B40, B50, B20AC2, B20AC4, B20AC6, B50AC2, B50AC4 and B50AC6 are provided for experiments. The dynamic and kinematic viscosity, density, HHV, and LHV of each fuel blends are determined immediately after fuel preparation. Tested fuel characteristics are listed in the Table 4. A S1100A2 single cylinder, four stroke, naturally aspirated, air-cooled diesel engine is coupled with hydraulic dynamometer resistance equipment, which can be controlled externally. The tests are performed at 1600 rpm under no load, 20%, 40%, 60%, 80% and full load engine. The schematic of set up and test procedures is illustrated in Fig. 2. For each test torque, power, fuel consumption, specific energy consumption (SEC), exhaust gas temperature, ambient temperature, ambient pressure, environment humidity are recorded and all data are determined. The engine is run for 10 min to ensure the removal of residual previous fuel blends in the fuel line. After that the readings is recorded. This procedure is repeated for all the blends. After the initial analysis and error estimation, some of the tests were repeated.



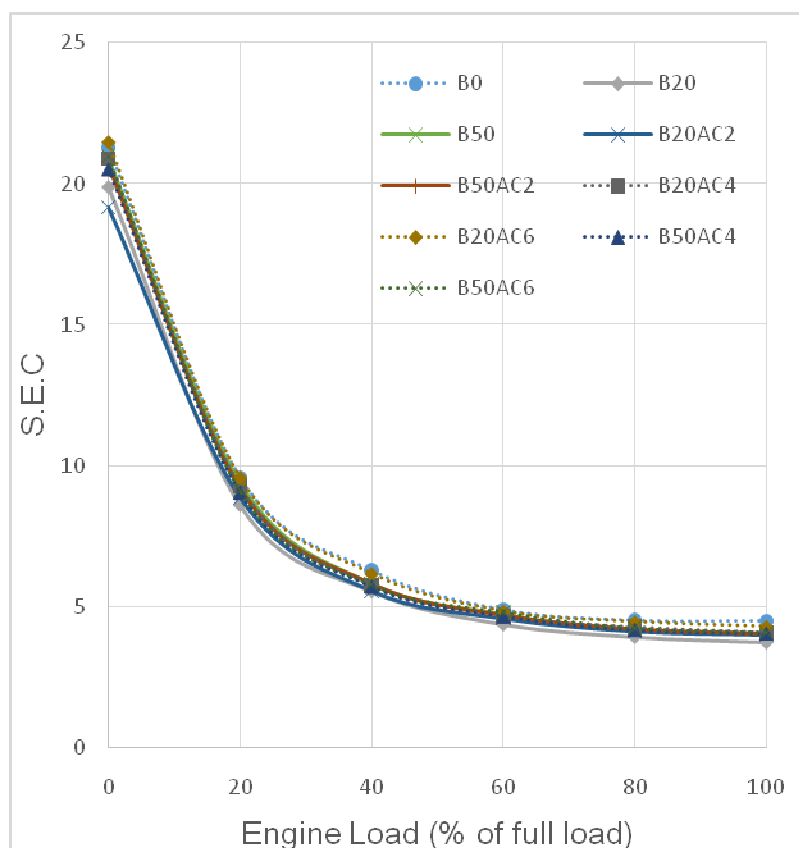
**Fig. 2.** Schematic of the experimental setup.

## RESULT AND DISCUSSION

### Analysis of Specific Energy Consumption (SEC)

Figure 3 shows the effect of acetone added to B20 and B50 on the SEC of engine. The fuel blends of B20AC2, B50AC2, and B50AC4 have the minimum SEC, while the B0 and B50 have the maximum SEC. This is due to the lower heating value of biodiesel. In this way, more fuel is used for the same power generation. Increasing

the share of biodiesel enhances the fuel density, and subsequently the heating value of the diesel-biodiesel is reduced [33]. In general, the additions of acetone to diesel-biodiesel blends improve the combustion and reduce the SEC. It is concluded that the added acetone in diesel-biodiesel blends will decrease on average 9.39%, 4.73%, and 5.68% of SEC in case of B20AC2, B50AC2 and B50AC4 fuel blends.



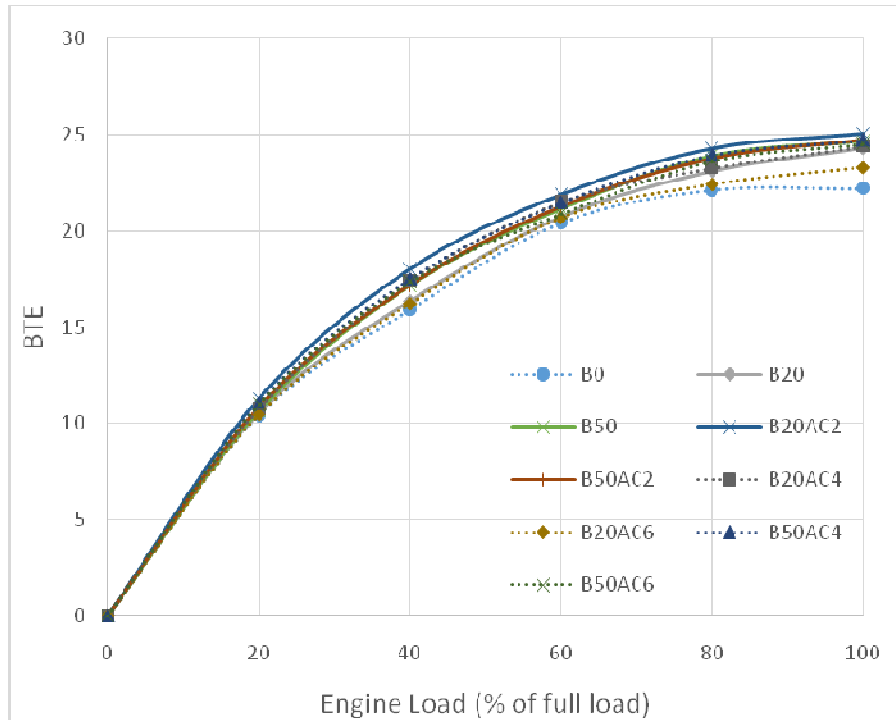
**Fig. 3.** Diagram of SEC at 1600 rpm.

### Analysis of Brake Thermal Efficiency (BTE)

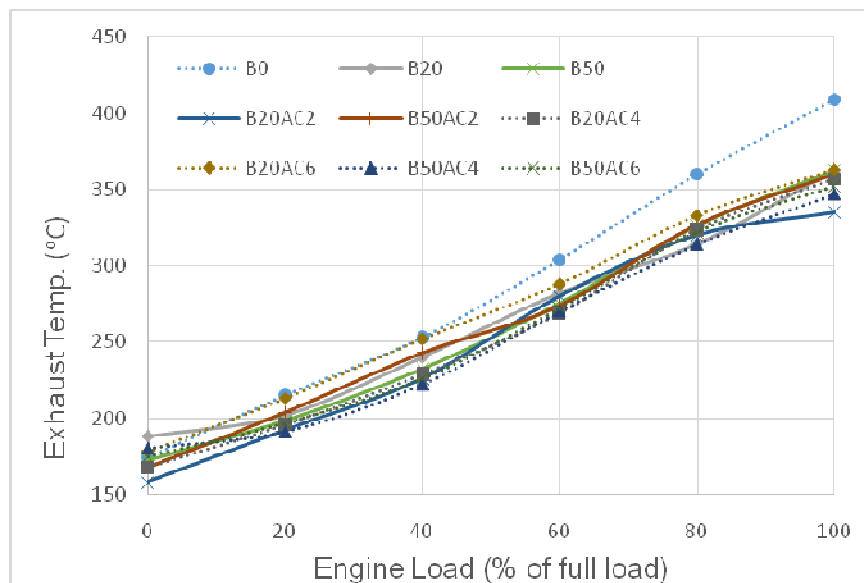
Figure 4 shows the brake thermal efficiency (BTE) values for all fuel blends. The lowest value of BTE is related to pure biodiesel, B20, and B20AC6 fuels. The maximum values of BTE are obtained for B20AC2, B50AC2 and B50AC4 fuel blends. Those of fuels that only are containing acetone (B20AC2, B50AC2, and B50AC4), have the lower BTE compared with those of fuels including only both diesel and biodiesel. Oxygen available in acetone significantly improves the brake thermal efficiency of the engine.

### Analysis of Exhaust Gas Temperature Fuel Blends

Figure 5 shows the effect of acetone share added to B20, and B50 blends on the exhaust gas temperature. Fuel blends of B0, B20 and B20AC6 have the highest exhaust gas temperature, whereas the B20AC2, B20AC4, B50AC4, and B50AC6 have the lowest exhaust gas temperature. B20AC2, and B20AC4 decreased the exhaust gas temperature by 11.895%, and 10.029% respectively on average.



**Fig. 4.** Diagram of BTE at 1600 rpm.

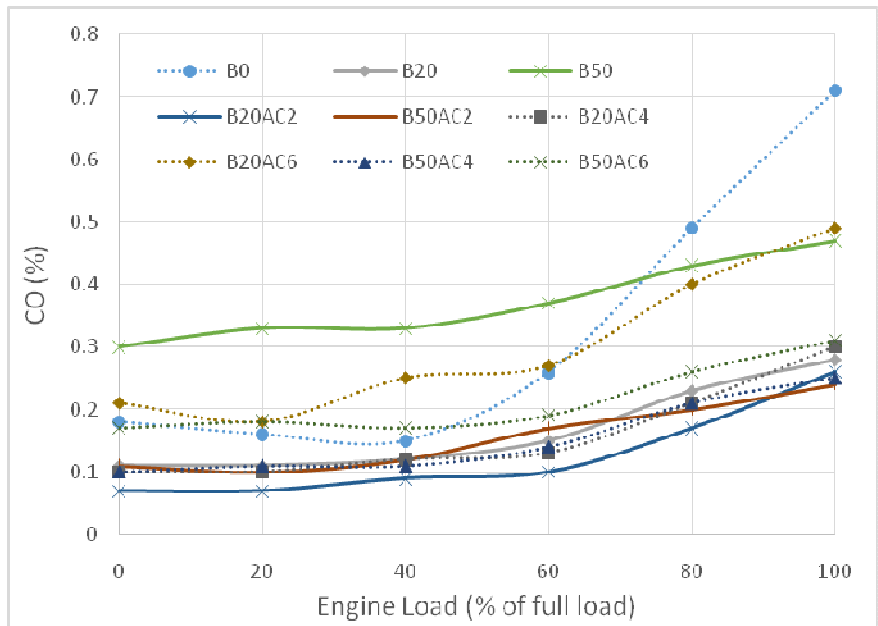


**Fig. 5.** Diagram of exhaust gas temperature at 1600 rpm.

### Analysis of Emissions

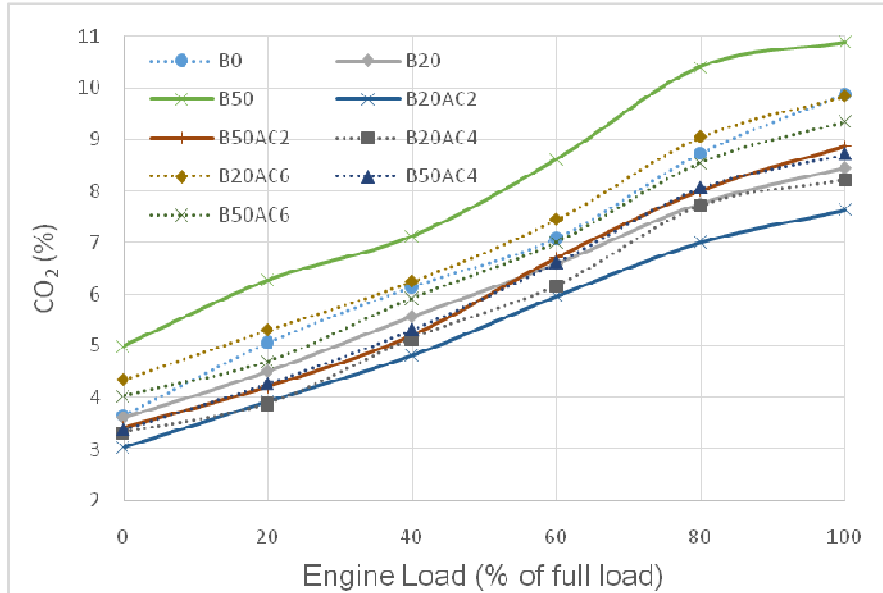
In Fig. 6, it may be seen that the combination of B20AC2, B20AC4, B50AC2, and B50AC4 have created the best conditions in terms of the lowest CO generation. The highest amount of CO emission is for B50, B20AC6, and B0 respectively. This can be attributed to the presence of oxygen in the fuel blends and more complete combustion that provides the best conditions for lower emission.





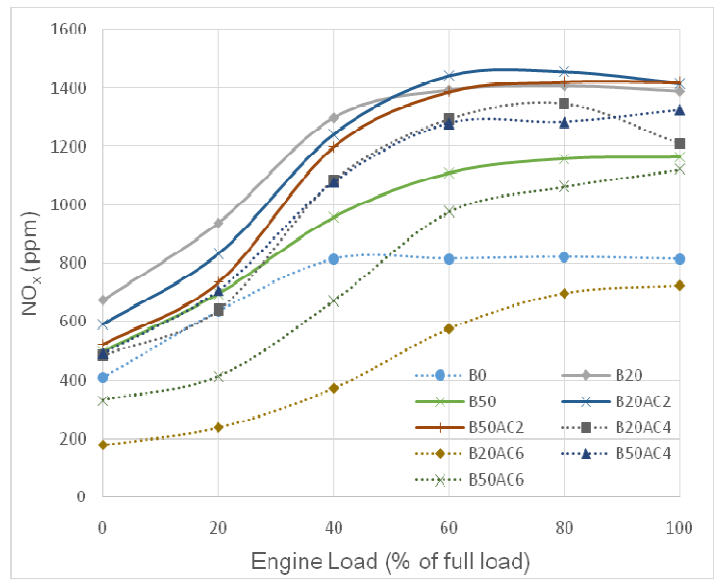
**Fig. 6.** Diagram of CO at 1600 rpm.

Figure 7 displays the CO<sub>2</sub> emissions for all fuel blends. This shows that the lowest values of CO<sub>2</sub> emissions are related to fuels of B20AC2, B20AC4, and B50AC4, respectively. The highest amount of CO<sub>2</sub> emission is for B50, B20AC6, and B0 respectively.



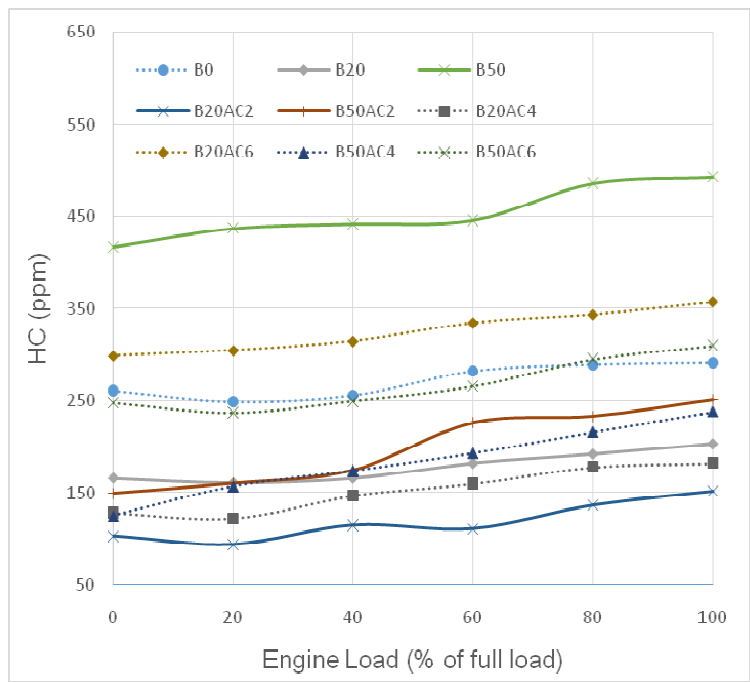
**Fig. 7.** Diagram of CO<sub>2</sub> at 1600 rpm.

According to Fig. 8, Most of the NO<sub>x</sub> content is for B20, B20AC2, B50AC2, B20AC4, B50AC4, and B50 fuels. And the least of the NO<sub>x</sub> content is for B20AC6, and B50AC6. All of these cases arise from complete combustion of fuel in the combustion chamber and increase of oxygen which is led to NO formation. CO<sub>2</sub> can be produced to avoid CO generation. A special fuel blend must be selected to form the best balance between NO<sub>x</sub>, CO, and HC emissions.



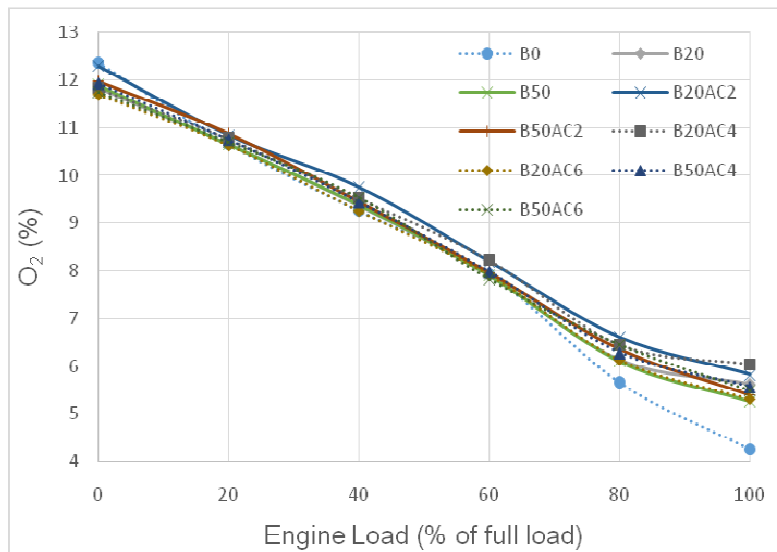
**Fig. 8.** Diagram of NO<sub>x</sub> at 1600 rpm.

Figure 9 shows that the lowest values of HC emissions are related to fuels of B20AC2, B50AC2, B20AC4, B50AC4, and B20 fuels. The highest amount of HC emission is for B50, B20AC6 and B0.



**Fig. 9.** Diagram of HC at 1600 rpm.

There is a negative correlation between the O<sub>2</sub> and CO. As shown in Fig. 10, the highest amount of oxygen is observed in fuels of B20AC2, B20AC4, B50AC2 and B50AC4. This shows that during fuel combustion, most of the oxygen is consumed in the blend and combustion is more complete. Maximum power production is related to these fuel blends, resulting in the lowest fuel consumption. The remaining half of the O<sub>2</sub> mole is involved in NO generation. The lowest O<sub>2</sub> content belongs to the B0, B50, and B20 fuel blends.



**Fig. 10.** Diagram of O<sub>2</sub> at 1600 rpm.

## CONCLUSION

A comprehensive experimental study was performed to compare and evaluate the performance and exhaust emissions characteristics of diesel, and diesel-biodiesel blends with acetone-diesel-biodiesel blends, which were used to fuel a direct injection diesel engine. The tests were conducted by using the above fuels with the engine at fixed speed and varying engine loads. Exhaust emissions such as NO<sub>x</sub>, CO, CO<sub>2</sub>, and O<sub>2</sub> and HC were measured for each test. Brake specific fuel consumption and BTEs were calculated to evaluate the engine performance. Thus, the following conclusions are drawn:

- Brake specific fuel consumption improved on average 9.39% using acetone-diesel-biodiesel blends than pure diesel. BTEs also improved on average 10.21% with the same additives.
- HC emissions reduced with the use of acetone additives but NO<sub>x</sub> emissions increased for all acetone-diesel-biodiesel blends with respect to diesel, and blends without acetone.
- Acetone-diesel-biodiesel blends showed overall improvement regarding performance and emission except NO<sub>x</sub> increased.

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