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Original Research Article

Experimental investigation of isopropyl alcohol (IPA) /diesel blends in a diesel engine for improved exhaust emissions

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Abstract

This study focuses on the effect of blending isopropyl alcohol (IPA) and diesel fuel with conventional diesel. The effect of isopropyl alcohol on a diesel engine was examined experimentally in a three-cylinder direct injection diesel engine running at a constant speed of 1500 rpm at different loads. 1% dodecanol was added into the mixture. From the results, it was seen that the CO, HC and smoke density emissions decreased, while NOx emissions and SFC increased with the increase in exhaust gas temperature.

Keywords: Isoprophyl alcohol (IPA); dodecanol; diesel engine; exhaust emissions

1. Introduction

Compression-ignition engines have been widely used as the source of power for engineering machinery, automobile and transport equipment due to their excellent drivability and thermal efficiency. However, compression-ignition engines are major contributors to various types of air pollutant emissions such as carbon monoxide, nitrogen oxides, particulate matter, and other harmful exhaust emissions [1-5]. The scarcity of conventional fossil fuels, growing emissions of combustion-generated pollutants and their increasing costs will make alternative fuels more attractive [6]. There are limited reserves of petroleum-based fuels concentrated in certain regions of the world. These sources are on the verge of reaching their peak production. Fossil fuel resources are diminishing day by day [7, 8]. Alcohol, which is one of the renewable energy sources and which can be obtained from agricultural biomass materials, has been tested intensively on I.C engines.

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Compared to diesel fuel, it is seen that alcohol is a simple compound. It does not contain sulfur or complex organic compounds [9,10]. Recently the economics have become much more favorable for the production of alcohol so it is able to compete with diesel fuel. Consequently, there has been renewed interest in alcohol–diesel blends with particular emphasis on exhaust emissions reductions. When considering an alternative fuel for use in diesel engines, a number of factors are important.

These factors include supply and distribution, the integrity of the fuel being delivered to the engine, emissions and engine durability [11]. Isopropyl alcohol contains more oxygen compared to diesel fuel. This situation provides a positive effect for combustion. Gasoline and diesel engines and fuel systems do not require significant changes in order to use methanol [12]. In this study, the effect of an isopropyl alcohol-diesel fuel mixture on exhaust emissions from a diesel engine was investigated.

2. Materials and methods

The experiment set was comprised of a

diesel engine, synchronous generator, precision scale, AC charging, exhaust gas analysis and smoke measurement devices. The engine used in the experiments was a three-cylinder, four-stroke, direct injection (DI), water-cooling diesel engine. The technical specifications of the engine are given in Table 1. The experimental apparatus for the engine consisted of the test engine, fuel injection system, AC load group and control systems, exhaust emissions and smoke density analyzer, as shown in Fig. 1. All tests were performed on the engine without modification. Before taking the measurements, the gas analyzer instruments were calibrated. The gas analyzer specification is given in Table 2 and Table 3. The physical and chemical properties of the test fuels are given in Table 4. Mixtures were prepared just before the tests. In this study, a mixture of isopropyl alcohol and diesel fuel was used as the alternative fuel. 100% pure standard diesel fuel was also used as the reference for making comparisons. Four different diesel fuels were prepared by adding 2, 8, 12 and 16% isopropyl alcohol into diesel fuel. 1% (by volume) of dodecanol was added into each blend to obtain a stabilized mixture. The engine was maintained at each speed and then the measurement results were recorded. All measurements were repeated at least three times at each speed. CO (%), CO_2 (%), HC (ppm) and NO_x (ppm) emissions were measured with a CAPELEC CAP 3200 gas analyzer. The smoke density (%) of the exhaust was measured with a CAP 3200 D LCD screen device. At the same time, specific fuel consumption (SFC), AFR and exhaust gas temperature were measured.

In the experiments, a synchronous generator with maximum active power of 12.5 kW was used to start the engine. The engine worked with standard fuel without a load for a period of time and when the engine reached the optimal temperature, 4 different levels of load -2.5 kW (20%) – 5 kW (40%) – 7.5 kW (60%) – 10 kW (80%) - were applied to the engine. Before starting the experiments, the fuel injection pump, the injection pressure, injection advance and the valve settings were calibrated according to the engine catalog values, and the engine oil was changed.

Table 1. Test engine specifications.

Item	INTER-IDE314NG
Spray system	Direct injection
Cooling system	Water-cooled with radiator
Number of cylinders	3
Bore x Stroke	80 x 90
Stroke volume (lt)	1,4
Compression ratio	18/1
Maximum power (kW/HP)	13,5 / 18

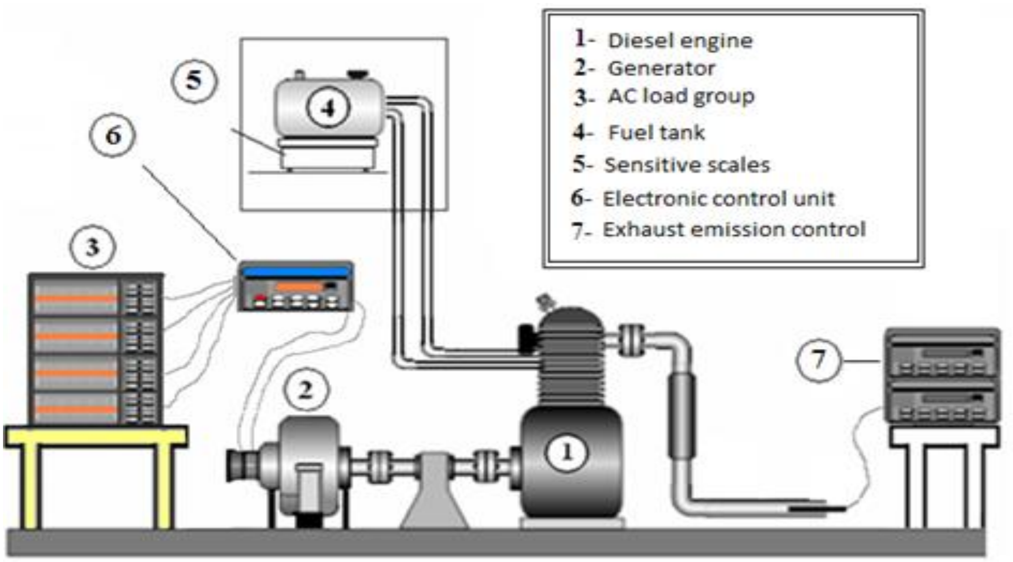

Figure 1. Schematic of test set-up.

Table 2. Exhaust emission measurement range and sensitivity of the measuring device.

Parameter	Measuring range	Sensitivity
HC	0 – 20000 ppm	1ppm
CO	0 – 15 %	0,001 %
O2	0 – 21,7 %	0.01 %
CO_2	0 – 20 %	0,1 %
Lambda	0,6– 1,2	0.001
NOx	0 – 5000 ppm	1 ppm

Table 3. Smoke density measurement range and sensitivity of the measuring device.

Parameter	Measuring range	Sensitivity
N	0 – 100 %	0.1 %
K	0.00 – 9,99 m–1	0.01 m–1

Table 4. Physical and chemical properties of the test fuels.

Property	Unit	Diesel Fuel	Isopropyl alcohol
Viscosity	Mpa.s	4,24	1,96
Density	Kg/ m^3	831,96	789,66
Flash Point	ºC	65,5	13
Cetane Index	-	53,1	-
Pour Point	ºC	-14	<-56
Lower clorific value	Cal/gr	9302	7851
Up Calorific value	Cal/gr	10951	7647

3. Results and Discussion

Figure 2 shows the variation in the CO emission levels for various test fuels at different load conditions.

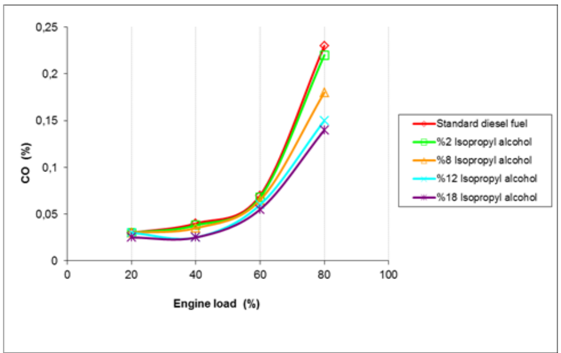

Figure 2. The variation of CO emission in relation with the engine load.

It was observed that the CO emissions increased with the load. It was also observed that the minimum CO emission value for all fuels was obtained at 20% of the engine load. The average decreases in CO emissions in the mixtures of isopropyl alcohol compared with that of the standard diesel fuel were determined to be 3.78% for 2/IPA, 16.0% for 8/IPA, 28.37% for 12/IPA and 33.78% for 16/IPA. It was also found that the CO emission level decreased with an increase in isopropyl alcohol percentage in the blend. Due to the presence of oxygen in isopropyl alcohol, there was a positive effect on the combustion. This condition is due to the combustion characteristics of isopropyl alcohol, i.e. lower ignition temperature, lower viscosity, lower carbon fraction and oxygen content.

The variations in smoke density in relation to the fuels used during a constant speed of 1500 rpm at different loads are shown in Fig.3.

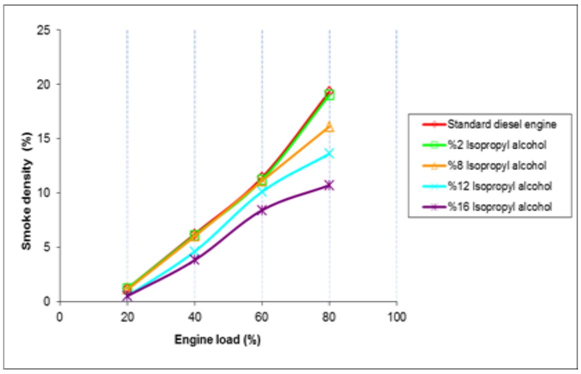

Figure 3. The variation of smoke density in relation with the engine load.

Soot formed as a result of carbon particles produced by incomplete combustion. The average decreases in smoke density in the isopropyl alcohol mixtures compared with that of the standard diesel fuel were determined to be 1.57% for 2/IPA, 8.66% for 8/IPA, 24.40% for 12/IPA and 38.58% for 16/IPA. Smoke density in the isopropyl alcohol mixtures was lower than that of the standard diesel fuel. As can be seen from the figure, the smoke density decreased considerably with the increase in the isopropyl alcohol percentage. The oxygen content of fuel can contribute to improved fuel oxidation in locally rich fuel combustion zones, hence resulting in the reduction of smoke [13]. However, smoke density differences increased at high engine loads. Combustion efficiency decreased with blended fuels at high engine loads. Although isopropyl alcohol has a lower calorific value, the lower carbon content of isopropyl alcohol enhances the probability of the lower smoke density.

Figure 4 shows the variation in the NO_X emission levels for various test fuels at different load conditions.

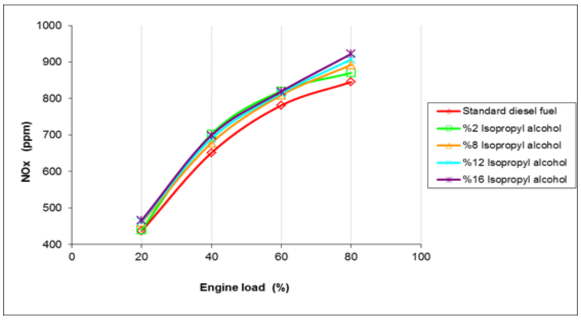

Figure 4. The variation of NOx emission in relation with the engine load.

An increase in NOx emissions was observed for all test fuels used in the isopropyl alcohol mixtures compared to the standard diesel fuel. Due to the presence of oxygen in the isopropyl alcohol, NOx emission levels increased. NOx emission levels increased rapidly at higher loads when compared to the minimal increase at lower loads. The higher combustion temperature at higher loads increased the NOx emissions. The average increase in NOX emissions in the isopropyl alcohol mixtures compared with that of the standard diesel fuel were determined to be 4.34% for 2/IPA, 4.60% for 8/IPA, 5.89% for 12/IPA and 7.07% for 16/IPA.

Figure 5 shows the variation in the HC emissions levels for various test fuels at different load conditions.

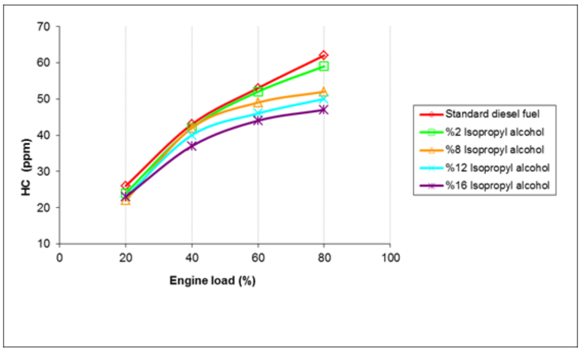

Figure 5. The variation of HC emission in relation with the engine load.

The HC emissions for all the fuels were tested at different loads regimes. For all the fuel blends, their emissions increased with an increase in loads. HC emissions are generally formed by unreacted fuel.

As shown in Fig. 5, HC emission levels were lower in the isopropyl alcohol mixtures compared with the standard diesel fuel at all engine speeds. Similar results have also been reported by other researchers [14, 15]. The increase ratio of HC emissions was generally higher at higher engine speeds. The average decreases in HC emissions in the isopropyl alcohol mixtures compared with that of the standard diesel fuel were determined to be 3.80% for 2/IPA, 10.32% for 8/IPA, 13.58% for 12/IPA and 17.93% for 16/IPA. In some research, alcohol was added to biodiesel to study the effect on HC emissions. For instance, Bhale et al. [16] found the HC emissions to be on average 12.4% lower than that of diesel.

The variations in CO_2 emissions in relation to the fuels used during a constant speed of 1500 rpm at different loads are shown in Fig.6.

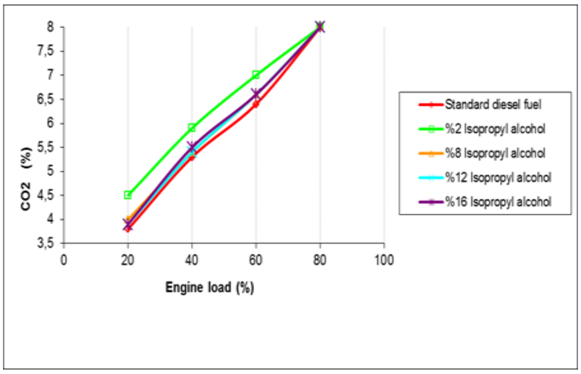

Figure 6. The variation of CO_2 emission in relation with the engine load.

From the experimental results, it is seen that the oxygen in alcohol combines with CO to form CO_2, thus increasing the amount of CO_2. This increase was 8.08% for 2/IPA, 2.12% for 8/IPA, 1.70% for 12/IPA and 2.12% for 16/IPA fuel. As shown in Fig. 6, CO2 emissions were higher with the isopropyl alcohol mixtures compared with the standard diesel fuel at all engine speeds. The CO_2 emissions for the isopropyl alcohol mixtures were on average 12.4% lower than that of diesel. These results indicate that the small amount of methanol in alcohol could increase the oxygen content of the blended fuel and reduce the viscosity and density of the blend so the HC emissions were reduced [17].

The variations in exhaust gas temperature in relation to the fuels used during a constant speed of 1500 rpm at different loads are shown in Fig.7.

The increases in exhaust gas temperature in the isopropyl alcohol mixtures, compared with the standard diesel fuel were determined to be 1.48% for 2/IPA, 2.97% for 8/IPA, 1.11% for 12/IPA and -0.37% for 16/IPA. The isopropyl alcohol mixtures had higher exhaust gas temperatures compared to the standard diesel fuel due to the higher oxygen content.

Figure 8 shows the variation in the AFR values for various test fuels at different load conditions.

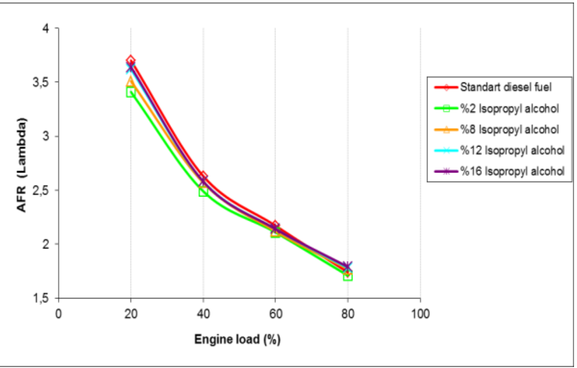

Fig.8. The variation of AFR values in relation with the engine load.

Fig. 8 shows the AFR values for all the test fuels. It can be seen that the AFR values displayed similar properties for all the test fuels. The decrease in AFR values in the isopropyl alcohol mixtures compared with the standard diesel fuel was determined to be 2.43% on average for all the test fuels.

The variations in SFC value in relation to the fuels used during a constant speed of 1500 rpm at different loads are shown in Fig.9.

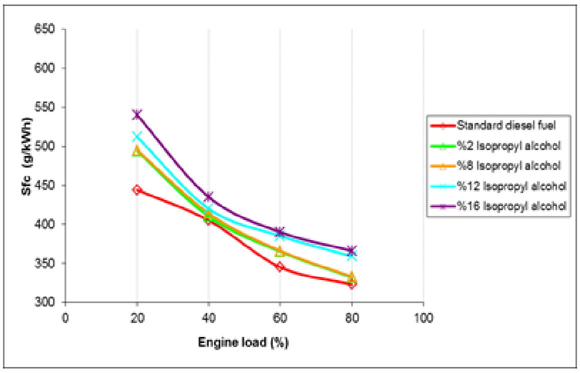

Figure 9. The variation of sfc in relation with the engine load.

As shown in Fig. 9, the SFC value was higher with the sopropyl alcohol mixtures compared with the standard diesel fuel at all engine loads. Similar results have also been reported by other researchers [14]. The average SFC value increases in the mixtures of isopropyl alcohol compared with that of the standard diesel fuel were determined to be 5.5% for 2/IPA, 5.99% for 8/IPA, 10.48% for 12/IPA and 14.10% for 16/IPA. Because the energy content of isopropyl alcohol is lower than that of the standard diesel fuel, if ignition delay time is longer, more fuel is introduced into the combustion chamber and evaporates during injection [18]. The rate of vaporization of the fuel droplets depends on the size of the droplets, velocity, and distribution, the pressure and temperature inside the cylinder, and the volatility of the fuel. Temperature is an important parameter for ignition delay [13].

4. Conclusions

In this study, it has been shown that properties of isopropyl alcohol–standard diesel fuel blends provide relevant information about their behavior as alternative diesel fuels. In general terms, it can be concluded that the tested isopropyl alcohol–diesel fuel blends presented similar properties values compared to those of standard diesel fuel.

The following conclusions may be drawn from the present study:

According to the results of the tests,

- Hydrocarbon emissions decreased with the use of isopropyl alcohol mixtures compared to standard diesel fuel.
- The use of isopropyl alcohol mixtures decreased smoke density mainly due to the higher oxygen content and there was a reduction in the heating value of isopropyl alcohol compared to standard diesel fuel.
- Because the oxygen content of isopropyl alcohol is higher than that of standard diesel fuel, the isopropyl alcohol mixtures caused an increase in NOx compared with standard diesel fuel. There was an increase of 5.47% for isopropyl alcohol mixtures compared with that of the standard diesel fuel.
- CO emissions decreased when using isopropyl alcohol mixtures due to the higher

oxygen content and the lower carbon-to-hydrogen ratio in isopropyl alcohol compared to standard diesel fuel. This decrease was 3.78-33.78% for isopropyl alcohol mixtures.

SFC and exhaust gas temperature increased with the use of isopropyl alcohol mixtures compared to standard diesel fuel.

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