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Experimental Investigation of 2nd Generation ethanol-blended Diesel Fuel in a Multi-cylinder Automotive CRDI Diesel Engine

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ABSTRACT: This study presents the utility of 2nd generation (2G) ethanol, blended with diesel fuel in a multi-cylinder automotive CRDI diesel engine. The fuel blends were prepared in different proportions of 2G ethanol in diesel fuel, out of which fuel blends with 7%, 13%, and 19% of 2G ethanol was found stable based on miscibility with diesel fuel. A multi-cylinder automotive CRDI diesel engine was operated to evaluate the performance and emission characteristics of 2G ethanol concentration in diesel fuel for this experimental study. For each tested fuel, the engine was run at a constant engine speed of 2000 rpm with varying load conditions. The experimental results showed that brake thermal efficiency was improved using 2G ethanol-blended diesel fuel with increasing engine load. Nevertheless, no significant change was observed in engine brake power considering 2G ethanol-blended fuel. NOx formation and smoke were reduced significantly with an increasing fraction of ethanol in diesel fuel. Using 2G ethanol in diesel fuel will also enlarge agricultural commodity markets and will create additional income from 2G ethanol produced from crop waste. In addition, by adopting 2G ethanol-blended diesel as a marketable fuel in India, stringent emission norms and government declarations can be prospered.

Keywords: Diesel, 2G ethanol, Fuel blending, Multi-cylinder diesel engine, Engine performance and emissions.

I. INTRODUCTION

The worldwide concern in regard to energy uncertainty, strongly increasing prices of petroleum and predictable commitments of conforming to the ever-stringent emission standards have wandered the consideration of fuel industry from traditional based fuels to new renewable fuels for IC engines which are more energy-efficient and generates a low level of harmful emissions. Adding on, the natural worry of a dangerous atmospheric devation and environmental change has incredibly expanded the interests of the application examination of biofuels for IC engines.

Ethanol is a kind of renewable fuel as it can be prepared from many kinds of raw resources such as sugar cane, maize, corn, sugar beets, etc. [1]. The properties and specifications of blended ethanol with diesel fuel were discussed by [2]. Exceptional accentuation is set on the blend properties basic to the impending business utilization of these blends. A significant volume of studies has been conducted on the performance and emission parameters of diesel engines fueled with blends of ethanol and diesel fuel in last past decade. Due to the specific prominence on cutting down the emissions, ethanol-diesel blends turn out to be more and more popular [3]. Rakopoulos *et al.*, [4] experimentally assessed the effects of using blends of ethanol with diesel fuel on the combustion and emissions properties. Authors from the same group further investigated the impacts of ethanol blended diesel fuel with 5% and 10% (by volume) of ethanol in diesel fuel on the performance and emissions parameters of a turbocharged, DI diesel engine [5]. The outcomes demonstrated hat carbon monoxide (CO) and oxides of nitrogen (NOx) emissions were reduced, Total Hydrocarbon (THC) emissions augmented with the utilization of ethanol. Growing ethanol level in the blended fuel augmented the Brake Specific Fuel Consumption (BSFC) and reduced the brake thermal efficiency (BTE).

Di *et al.*, [6] explored the effect of adding ethanol (2%, 4%, 6% and 8% in volume) to diesel fuel with ultra-low sulfur content on the exhaust emissions of a diesel engine with direct injection. With the growing volume of ethanol in the fuel blends, the BTE improved marginally. THC and CO emissions were decreased whereas NOx formation was increased when contrasted with the diesel fuel. Huang *et al.*, [7] examined the performance and emissions characteristics of a diesel engine with 10%, 20%, 25% and 30% of ethanol blended with diesel fuel. The results demonstrated that the BTE was decreased with increasing ethanol fraction in the blended fuel because of the ethanol's Lower Heating Value (LHV). The smoke emissions were low throughout with ethanol blended diesel fuel as compared to the emissions from diesel fuel.

Though, 1st generation (1G) ethanol seems to make some suspicion to specialists. There are stresses over its biological impacts, which set limitations in the growing creation of 1G ethanol. The fundamental shortcoming of 1G ethanol is the food-versus-fuel debates. The combined denigration of the manageability of numerous 1G ethanol has raised consideration regarding 2G ethanol. As the feed stocks of 1G ethanol generate the difficulty of influencing the food stuff cost structures.

Whereas the feedstock of 2G ethanol is mainly agricultural unwanted trashes such as sugarcane waste, rice straws, cornstover and the non-edible portions of plants [8]. The raw material used in the production of 2G ethanol overcome the two main conflicts for the 1G raw material like divergent effects on food cost and the inability to gauge. The benefit of the utilization of 2G ethanol-blended diesel fuel is that the prepared blends come to be an oxygenated fuel blend. So, the content of oxygen in the fuel blends will result in complete combustion which will consequence in low-level production of pollutant emissions [9].

The decision of the 2G ethanol-blended diesel fuel origin to be utilized basically relies upon its compliance with the fundamental fuel provisions for diesel engine implementation. In this observation, the entrance to edification on the physical and chemical properties of the 2G ethanol-blended diesel fuel was investigated by Singh and Bharj [9] which settled the hypothesis for the development of 2G ethanol-blended diesel fuel.

A. The objective of the study

The objective of this study is to examine the utility of 2G ethanol-blended diesel fuel in a multi-cylinder automotive CRDI diesel engine and to relate the performance and emission parameters with commercial diesel fuel.

II. MATERIAL AND METHODOLOGY

A. Test fuels and their properties

In the experimental study, different blends with a varying fraction of 2G ethanol in diesel fuel were developed. From the prepared combinations, blends with 7%, 13% and 19% of 2G ethanol were observed to be steady based on miscibility as shown in Fig. 2 (a). Along with blends of 7%, 13%, and 19% of 2G ethanol-blended diesel fuel and diesel fuel were studied for their physio-chemical properties and related to prevailing international fuel standards. The examined fuels along with the measured properties are shown in Fig. 1.

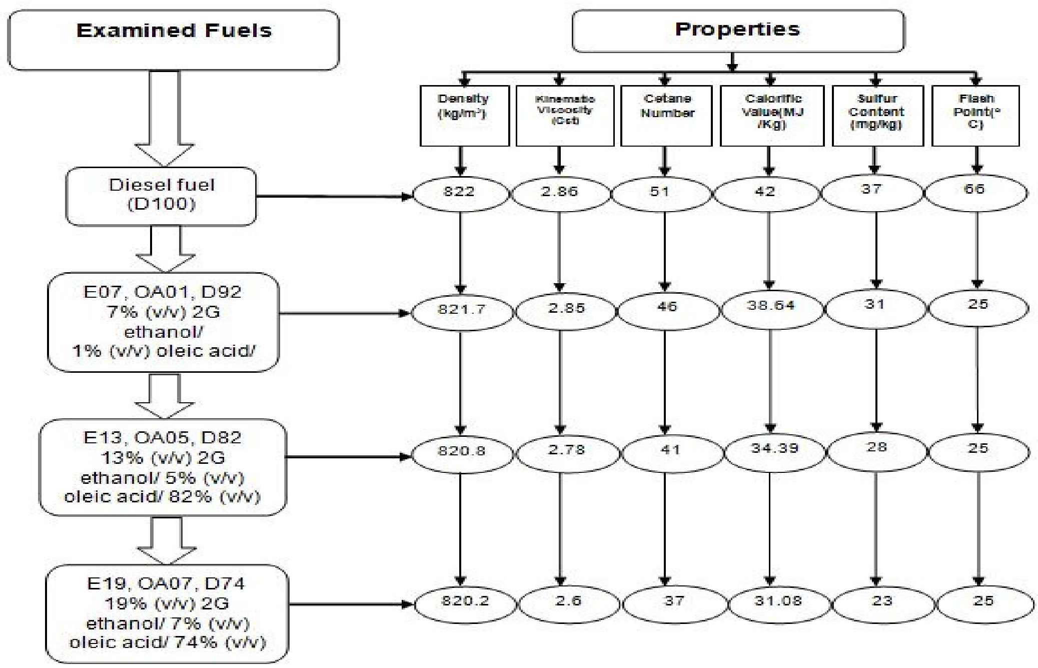

Fig. 1. Examined fuels along with the measured properties [9].

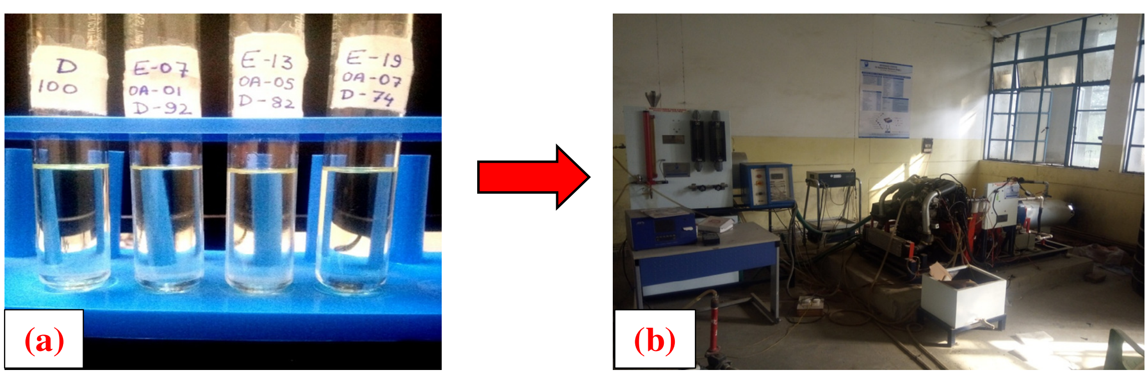

Fig. 2. (a) Diesel and 2G ethanol-blended diesel fuel samples (b) Lab setup of a multi-cylinder automotive CRDI diesel engine.

B. Experimental setup

The experimental study has been performed on the four-cylinder automotive CRDI diesel engine which is water-cooled and equipped with open ECU. The engine set up is coupled to an eddy current dynamometer. The engine set up is fully instrumented, which allows the measurement and control to the injection pressure, injection timing and boost pressure with the help of open ECU model MCP 4-I7 whose specifications are shown in Table 2. Exhaust gas emissions were measured with the AVL 4000 Di-gas analyzer. The experimental set-up of the engine test bed is shown in Fig. 2 (b). Details of the main specifications of the engine are given in Table 1. Experiments were conducted with diesel fuel and different blends of 7%, 13%, and 19% of 2G ethanol-blended diesel fuel. Moreover, all tests were undertaken with a constant engine speed of 2000 rpm. For accuracy of the test results all tests were repeated and average values were calculated. The engine was kept running for 15 minutes using diesel fuel for proper warm-up of the testing apparatus and before it's working on 2G ethanol-blended diesel fuel samples. Similarly, the engine was run using diesel before it was shut down. These steps ensured the engine free from 2G ethanol-blended diesel fuel before scheduling of the subsequent experimentation.

Table 1: Technical Specifications of Engine Test Rig.

S. No.	Description	Specification
1.	No. of Cylinders	04
2.	Volume	1994 cc
3.	Bore x Stroke (mm)	84.45 X 88.95
4.	Compression Ratio	17.5:1
5.	Cooling	Water Cooled (Mechanical Fan)
6.	Fuel Injection	Common Rail Direct Injection
7.	Injection Pressure	1600 bar (Max.)
8.	Turbocharger	VGT – Variable Geometry Turbocharger (ECU Controlled)
9.	EGR	Cooled, Progressive, Closed Loop (ECU Controlled)
10.	Injectors	Piezo Technology
11.	Injector – No. of Holes	08
12.	Torque/Power	260 Nm @1750 – 2500 rpm, 100 hp@4000 rpm

Table 2: Technical Specifications of open ECU.

S. No.	Description	Specification
1.	Operating Voltage	12V
2.	No. of Connectors	02
3.	No. of Pins	105 + 91 = 196
4.	Type	Open (Configurable through PC based Software)
5.	Analog Inputs	30
6.	Digital Inputs	15
7.	PWM Outputs	18
8.	Relay Outputs	4 (Low Side)
9.	H – Bridge	4
10.	Injector Driver	Piezo (4)
11.	Communication	CAN Bus

III. RESULTS AND DISCUSSION

As mentioned above, the experimental tests were carried out on a multi-cylinder automotive diesel engine fired with diesel fuel and blends of 2G ethanol at a constant speed of 2000 rpm. Various performance and emission parameters were recorded and analyzed during the experimentation. The results are shown and discussed in the subsequent paragraphs.

A. Brake Power

Fig. 3 shows the engine Brake Power (BP) with respect to the varying load during the experiments. It can be seen from the figure that no significant change is observed in engine BP up to 19% of 2G ethanol concentration in diesel fuel. The results showed that engine power can be sustained with different blends of 2G ethanol. In addition to this, after 60% loading conditions, the engine BP, further decreases in 13% and 19% concentration of 2G ethanol in the blended fuels. This is because as the load increases, the combustion of the fuel is disturbed. Whereas, the blend with 7% concentration of 2G ethanol has shown better engine BP then diesel fuel throughout the loading conditions due to its proper in-cylinder combustion.

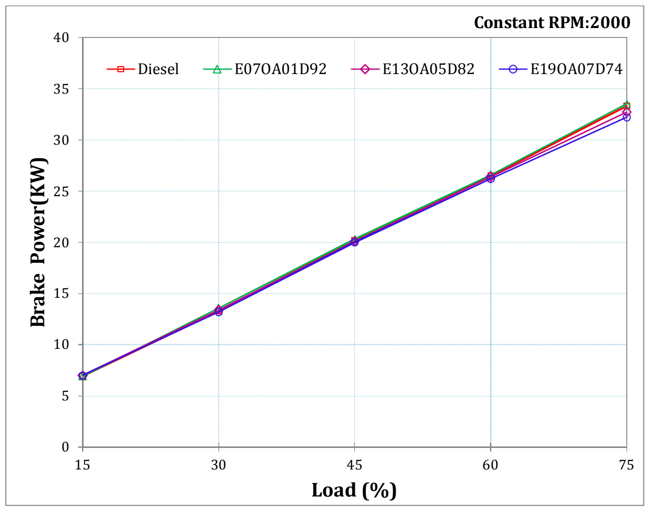

Fig. 3. Brake power with respect to varying load.

B. Brake Thermal Efficiency

The experimental results showed that BTE is improved using 2G ethanol-blended diesel fuel with increasing engine load conditions. Further, adding 2G ethanol has a positive effect on diesel fuel combustion as it delivers the major part of the engine's energy supply, increasing the BTE. A similar observation was noted by Jamrozik [10]. It can be seen from Fig. 4 that fuel blends with 7% and 13% concentration of 2G ethanol have shown better BTE than diesel fuel throughout the experiments with varying load conditions. Whereas, the blend with 19% concentration of 2G ethanol has shown comparable BTE with diesel fuel. It appears that higher efficiency values obtained for the blends compared to pure diesel fuel are due to the increase in the rate of combustion. The increasing 2G ethanol content in the blends supplies the chemically effective oxygen to the combustion chamber. This leads to an increase in the variable temperature in the outburst zones at the early stages of the combustion process.

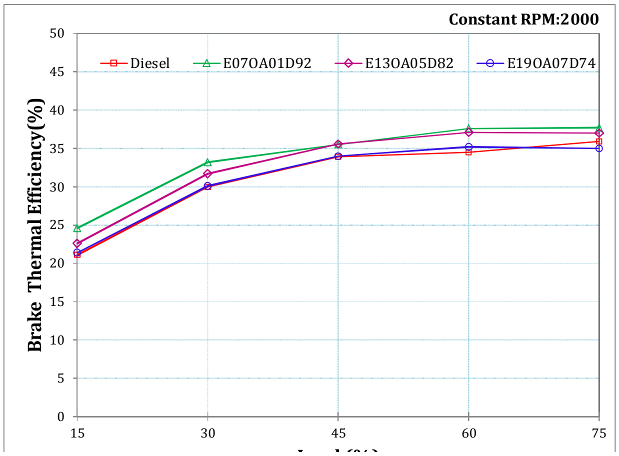

Fig. 4. Brake thermal efficiency with respect to varying load.

C. Brake Specific Fuel Consumption

Fig. 5 shows the test results of the BSFC when the engine is fired with different blends of 2G ethanol and diesel fuel. The addition of 2G ethanol in diesel fuel showed a rise in engine BSFC. It is due to the lower heating value of 2G ethanol as compared to diesel fuel. So, more fuel is required to produce the same amount of power as related to diesel fuel. Looking at the overall pattern, with increasing load conditions, BSFC decreases with all the tested blended fuels. This is because, as the load on engine increases, fuel consumption also increases, but the brake power output surpasses the fuel consumption increase which tends to show an overall fall of BSFC in the higher loading conditions of the engine. Fig. 5 shows the pattern of increase in fuel consumption with the increase of 2G ethanol percentage in the blended fuel. The results coincide with the previous work reported by Huang *et al*., [7].

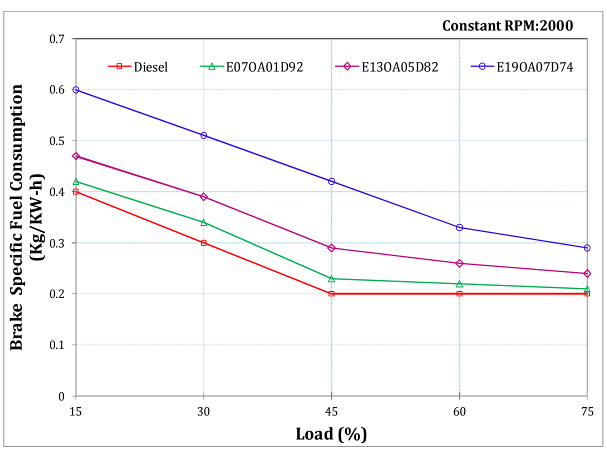

Fig. 5. Brake specific fuel consumption with respect to varying load.

D. Exhaust Gas Temperature

High exhaust temperature combined with lean combustion will result in the formation of poisonous and environmentally harmful oxides of nitrogen oxide. The exhaust gas temperature trend with respect to the varying load can be seen in Fig. 6. It was found that the engine's exhaust temperature using conventional diesel fuel was higher than 2G ethanol-blended fuels. The lower exhaust temperature for the prepared blends indicates lower production of NOx as shown in Fig. 7. The oxygen content of 2G ethanol-blended diesel fuel helps in making the combustion smoother in the combustion chamber. The higher level of oxygen availability due to more concentration of blends in diesel fuel results in complete combustion and hence lowers exhaust gas temperature. It can be seen in Fig. 6 that the exhaust gas temperature is least with the blended fuel having 19% of 2G ethanol.

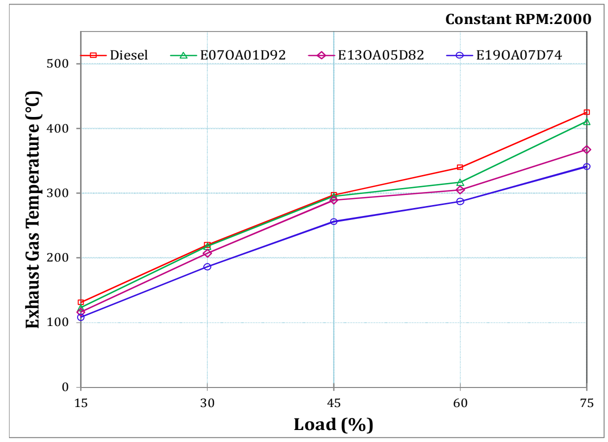

Fig. 6. Exhaust gas temperature with respect to varying load.

E. NOx Emissions

The test results for the NOx emissions from the engine are shown in Fig. 7. The engine's NOx emissions were lower than of diesel fuel when fueled with different blends of 2G ethanol. The results from experimental runs showed that even by varying the engine load the trends of NOx formation were uniform throughout the testing conditions. The blending of 2G ethanol in diesel fuel has shown better results than diesel fuel alone. As discussed in the previous Fig. 6, engine exhaust with lower gas temperature will produce a lower level of NOx whereas higher exhaust gas temperature will result in higher NOx emission. So, as the percentage of 2G ethanol is increased in the prepared blends the level of NOx emission is reduced accordingly.

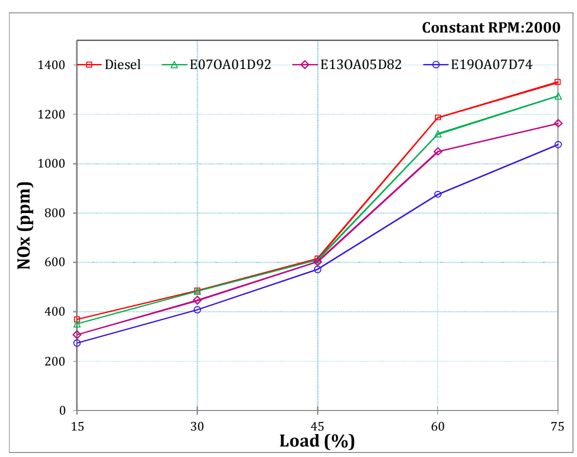

Fig. 7. NOx emissions with respect to varying load.

F. Smoke Emissions

Smoke opacity reveals emissions of dry soot which is one of the key components of particulate matter. The results of smoke emissions are shown in Fig. 8. The result shows that the engine smoke emissions were reduced throughout all the loading conditions with the use of blended fuel. The higher level of 2G ethanol in the blended fuel will result in a greater reduction in smoke emissions. This can be enlightened as due to the presence of fuel oxygen tends to reduce the possibility of rich zone formation and supports in oxidizing soot core during the combustion of fuel [11]. It is recorded that the reduction in smoke emissions by using blended fuel with 7% of 2G ethanol concentration was about 65% as compared to diesel fuel. Similarly, 79% and 83% reduction were noted with blends of 13% and 19% of 2G ethanol concentration, respectively. It can be seen from Fig. 8 that a sudden fall in smoke emissions is observed with all the fuels at 60% loading conditions. The possible reason is to optimize the engine combustion and reduce the vibrations for smooth engine operations. For this, the boost pressure was increased in the combustion chamber of the engine, due to which more air intake caused complete combustion of fuel inside the combustion chamber. Similar trends of smoke opacity were found in the study of Li *et al.,* (2009) [12].

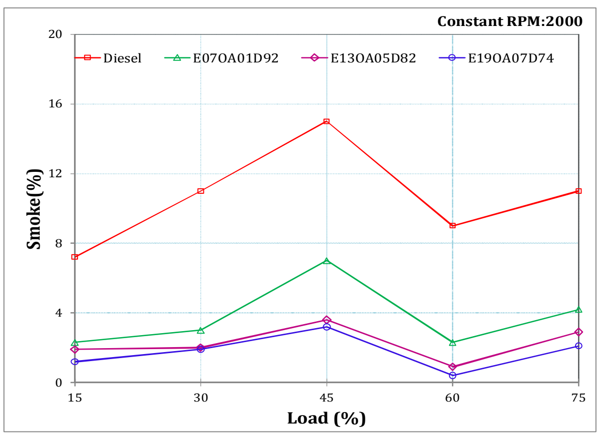

Fig. 8. Smoke emissions with respect to varying load.

IV. CONCLUSIONS

In this study, the experiments were conducted using diesel and 2G ethanol-blended diesel fuel under the constant speed of 2000 rpm with the varying load to investigate the impact and utility of 2G ethanol on the performance and emission characteristics of a multi-cylinder automotive diesel engine. Based on the experimentation, the following specific conclusions have been drawn.

— No significant change in engine BP is observed considering 2G ethanol-blended diesel fuel in a multi-cylinder diesel engine up to 19% of 2G ethanol concentration.

— The engine BSFC was increased by using 2G ethanol-blended diesel fuels due to the lower heating value of 2G ethanol with respect to the diesel fuel.

— BTE of the engine fueled with 2G ethanol-blended diesel fuel was improved by increasing the 2G ethanol concentration in the blends. Blends with 7% and 13% of 2G ethanol concentration have shown an overall rise of 8.5 % and 5.5% in the BTE of the engine with relating to diesel fuel. Whereas, blend with 19% of 2G ethanol concentration has shown a negligible rise of 0.20 % in the BTE compared to diesel fuel.

— The exhaust temperature of the engine using conventional diesel fuel was found to be higher than in the case of any 2G ethanol-blended fuel ratio. Sub sequentially, NOx emissions of the engine were reduced with different 2G ethanol-blended diesel fuel.

— The engine smoke emissions were decreased remarkably for different engine loading conditions. The maximum reduction of 83% in smoke emissions was recorded with 19% of 2G ethanol-blended diesel fuel.

Based on the findings of the present study, it is understood that 2G ethanol-blended diesel fuel can be utilized up to 19% of the concentration in an automotive diesel engine. The use of 2G ethanol in diesel fuel results significantly in retaining the engine BP and improves engine BTE along with reducing the levels of harmful poisonous gases from the tailpipe of the diesel engine. In over-all the consequences of the study identify the potential of 2G ethanol for achieving a more cost-effective and eco-friendly alternative fuel.

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Conflict of Interest. The authors declare that they have no conflict of interest.

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