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Research Article

Multiparametric Optimization on Influence of Ethanol and Biodiesel Blends on Nanocoated Engine by Full Factorial Design

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Energy conservation and management have become critical industrial activities, since energy expenses account for a significant portion of production costs. This proactive strategy has had an effect on worldwide energy consumption trends. Integration of thermal barrier coatings into engine design is necessary to solve efficiency concerns, and this coating technology has the potential to increase engine power while lowering specific fuel consumption. In a similar line, biodiesel has been presented as a possible substitute to diesel since it is nontoxic and sourced from renewable energy sources. The present study aims to enhance the performance of a diesel engine via the use of a thermal barrier-coated piston that works on biodiesel mixes. Due to its outstanding thermal insulation qualities, yttria-stabilized zirconia is the preferred material for thermal barrier coatings. Brake thermal efficiency for B20E15 is about 4% better than diesel and for B20E05 and B20E15 is about 4.6% and 13.5% less fuel consumption. CO and HC emissions were reduced by 6% to 8% on average with the B20 blends. Biodiesel blends were compared to pure diesel in terms of performance and emissions, and the blend ratio was improved using a design of experiment tool.

1. Introduction

In today's rapidly evolving technological world, energy is vital to a country's growth. It is also used to measure economic and social progress. In particular, per capita energy consumption is used to assess a country's wealth. Globally, most issues of careless energy use have been tackled by the industrial revolution in the last century. Most nations' technological advancement is linked to increased energy consumption, industrial development, and less efficient use of energy sources [1]. Energy conservation and management have become essential industrial activities since energy is a substantial component of production costs. This constructive approach has impacted global energy use patterns. Thus, rich nations' production has increased, but their energy consumption has remained stable. Finally, renewable energy sources are equally relevant and significant in today's fast-growing globe, particularly since they are local and create fewer emissions. Using these resources to their full potential may significantly reduce pollution [2].

Studies on internal combustion engines are ongoing to reduce fuel and operational expenses as well as fuel consumption. With the advent of advanced ceramics technology, one of the methods to improve engine efficiency is via structural alterations. These coatings were first used on gas turbines and aeronautical engines [3]. Improved ceramic coatings may improve engine performance and reduce emissions by reducing heat rejection from the combustion chamber. Aside from that, as much fuel energy as feasible should be turned into useable mechanical energy. To attain these outcomes, the engine combustion chamber must be covered with low-heat-transmitting modern ceramic materials that may enhance cylinder temperature and pressure [4].

Alternative fuels for I.C. engines have been studied globally. Performance studies have proven the appropriateness of hydrogen, alcohols, biogas, producing gas, and different edible and nonedible oils. However, in India, bio-based fuels including vegetable oils, bio-alcohols, and biogas may be widely employed to alleviate fuel shortage issues [5]. Many different biodiesel blends are being developed and utilized in diesel engines to enhance performance and emissions. Linseed oil, rubber seed oil, and ternary biodiesel mixes are among the mixtures being tried in diesel engines. Diesel engines emit more carbon and nitrogen than gasoline engines [6].

Vegetable oils may be used in diesel engines without any changes by just mixing them with the fuel. Density, viscosity, volatility, and heating value are all improved by the process of blending. Counter flow heat exchangers may be used to preheat rubber seed oil by capturing the heat from exhaust gases. Preheated rubber seed oil improved engine analysis and exhaust emissions, according to the researchers. At all loads, warmed mixes had greater nitrogen emissions than plain rubber seed oil [7]. The performance and emissions of biodiesel made from rubber seed oil will be put to the test in a diesel engine using calcined eggshells as a heterogeneous catalyst, and their performance and emissions will be evaluated. The emissions of a diesel engine employing synthetic biodiesel were studied [2].

The combustion parameters affect power output, exhaust emissions, fuel consumption, engine vibration, and noise. The temperature and pressure of compressed air influence the ignition delay. While compression is occurring, the cooling system absorbs a lot of heat. Thermal barrier-coated engines may reduce heat loss and increase workable output with low heat conduction and high temperature resistance materials covering the combustion chambers [8].

Coating engine components with zirconia reduces heat conductivity. In conclusion, using ethanol as a fuel with a glow plug reduces exhaust pollutants but reduces efficiency compared to using diesel fuel. However, the engine's thermal efficiency improves somewhat with delayed injection timing. This improves thermal efficiency and decreases carbon monoxide and unburned hydrocarbon emissions while increasing nitrogen oxide emissions due to greater combustion temperatures [9]. Thermal barrier coatings on different engine components have gained traction in recent years because of their enhanced thermal and mechanical efficiency, reduced pollutants, and reduced fuel consumption. Soot precursors in hydrocarbon combustion may be oxidized using the waste heat that is rejected from the engine via insulation, thereby reducing emissions [10]. High melting points, strong adhesion, and wear resistance properties make ceramic materials ideal for use in high-temperature applications. On the basis of their qualities, ceramics may be used to cover combustion chamber components. In the combustion chamber, a covered engine retains heat better than a naked engine. As a result, less pollution and less fuel are produced [11].

When utilizing diesel and palm oil biodiesel, the impact of a thermal barrier coating including zirconia and aluminum silicate in conjunction with a NiCrAl bond coat on engine performance and emission analyses was investigated. Coated engines were found to have the lowest emissions of both diesel and biodiesel fuels [12]. A study compared two coated pistons with two coating thicknesses against a noncoated piston. The impact of biofuel was seen by comparing the results of experiments done using diesel as a fuel for coated and noncoated pistons, respectively. As coating thickness increases, thermal efficiency, fuel consumption, and pollutants decrease [13]. In grey relational analysis optimization approach, a copper alloy-coated diesel engine has been improved to improve performance and reduce emissions. When compared to an uncoated piston type engine, the improved copper chromium zirconium catalytic-coated piston generates fewer emissions and enhances performance [14].

The purpose of this research is to explore the effects of ethanol on rubber seed biodiesel blends with pure diesel at concentrations of 20% and 30%. In this study, a single-cylinder diesel engine is subjected to various load circumstances in order to determine its performance and emissions. The findings of the experiment tool "full factorial design" were optimized for mixes of biodiesel and ethanol in terms of fuel consumption, hydrocarbon emissions, and carbon monoxide emissions.

2. Material and Methods

Biodiesel offers a number of advantages over other alternative fuels due to its similarity to petroleum-derived diesel fuel. Many oil companies utilize biodiesel instead of diesel, which is equivalent to conventional petroleum fuels in engine efficiency, power production, uphill climbing, and hauling. In cold weather, biodiesel will fog and gel like regular diesel [15].

Natural rubber production in India ranks fourth in the world. Rubber latex, a valuable plantation commodity for the Indian economy, is harvested from the rubber tree. Rubber seed oil is an important byproduct of the rubber tree and is obtained by crushing and filtering the rubber seeds. In addition to natural rubber, the rubber tree produces a wide range of other goods. Rubber seed oil content varies from region to region, but on average, the oil output is 40%. Some businesses, such as soap and lubricating oil, are allowed to use rubber seed oil commercially, but most are prohibited. Rainfall, moisture, and bright sunlight are the primary reasons for its high demand. Unsaturated fatty acids make up about 75 to 85 percent of the rubber seed oil's composition [6].

Rubber seed oil has a calorific value of 39,800 KJ/kg, equal to diesel fuel. Rubber seed oil has a higher flash point than diesel but a viscosity ten times that of diesel. Finally, most research shows that rubber seed oil may be utilized as a substitute for petroleum diesel in a compression ignition engine. For CI engines, the higher the amount of carbon and hydrogen, the better the fuel quality and calorific value. The lower the sulfur concentration, the fewer sulfur oxides are formed, resulting in less pollution from exhaust fumes and fewer corrosive effects on engine components [5].

Rubber seed oil has a greater calorific value than other biofuels because it contains more carbon and hydrogen. There is no deposit and little heat loss due to the high calorific value. Rubber seed oil also has a high oxygen concentration, which minimizes CO emissions and unburned hydrocarbons. Because of its natural qualities, rubber seed oil may be used as a diesel engine replacement. It is utilized as an alternative fuel in rural regions, particularly for agricultural activities and irrigation equipment operation, apart from its principal use in engines. Overall, rubber seed oil is a simple and easy-to-utilize renewable energy source. It is also a low-cost fuel that is simply deployed and is environmentally friendly [7]. Table 1 displays the properties of rubber seed biodiesel and ethanol.

The piston coating is significant because its thermal expansion rate is different from other ceramic materials. Materials that provide good results include ZrO_2 stabilized with Y_2O_3 and ceramic coatings. ZrO_2 stabilized with MgO may be used safely in cylinder heads and intake exhaust valves. The composition of the binding layer is also critical in ceramic coatings, bonding materials to avoid hot corrosion and resistance. The use of NiCrAlY as a binding layer improves coating durability [16].

Thermal conductivity and expansion coefficient of ceramic materials are all poor at elevated temperatures. This means that less heat is dissipated from the combustion chamber components than with metals or metal alloys. Thermal barrier materials for covering combustion chamber components may be chosen from a small number of ceramic substances depending on their noteworthy qualities. Because heat loss is slowed, the coated engine will be capable of retaining the most heat at high combustion chamber temperatures. Using a high temperature will aid in full combustion, decrease emissions, and reduce the amount of fuel used [17].

The features of these materials, such as melting points, temperature transition minima, coefficients of thermal expansion, chemical composition, and compatibility with metallic substrates, all played a role in their selection. Thermal insulation for an internal combustion engine is provided by yttria-stabilized zirconia (YSZ) coated to a thickness of 200 m in the present experiment. There are a variety of ways to insulate a surface. The plasma spraying is used to coat YSZ, in which powdered YSZ enters as the phase, melts, and steers toward the piston, where it coagulates as a thick coating [8].

3. Experimental Details

Diesel engines are more efficient and utilize less fuel than gasoline engines owing to greater compression ratios, leaner air-fuel combinations, and reduced pumping losses. Developing nations like India increasingly depend on diesel engines to move people and products. This increases fuel usage, foreign currency outflows, and environmental concerns. Biofuels that are renewable and have characteristics similar to diesel might solve these issues [1].

A single-cylinder, constant-speed direct-injection engine was used to evaluate rubber seed biodiesel with ethanol blends. The results are displayed in Figure 1. The speed of the diesel engine is maintained independent of the load and the proportion of biodiesel in the fuel. The engine was connected to an eddy current dynamometer, which varied the loads from 0% to 100%. Every testing mixture is subjected to an additional 25% load increase in accordance with the engine power output of 4.2 kW. An eddy current dynamometer is used in order to manually alter the engine loads. In this experiment, a calibrated orifice on an air drum and a calibrated burette were used to monitor airflow and fuel flow rates, respectively. Both diesel and an esterified rubber seed biodiesel/ethanol mix were used to measure the flow of fuel, with the flow of each being recorded, in order to get different readings and results while the test rig was in use, with AVL software.

This study focuses on the influence of an ethanol additive on nanocoated pistons fuelled with rubber seed biodiesel. Biodiesel obtained from the transesterification process of rubber seed biodiesel was blended with diesel at different ratios of 20% and 30% on a volume basis, along with oxygenated additives of ethanol at 5% and 15% as B20E05, B20E15, B30E05, and B30E15. The biodiesel fuel named for the nanocoated low heat rejection engine (LHR) as LHRB20E05 is formed by the blend of 20% rubber seed biodiesel (B20), 5% ethanol on a volume basis, and mixed with pure diesel of 75%. The biodiesel fuel blends are prepared as LHRB20E15 (65%diesel + 20%rubber seed biodiesel + 15% ethanol), LHRB30E05 (65%diesel + 30%rubber seed biodiesel + 5%ethanol), and LHRB30E15 (55%diesel + 30%rubber seed biodiesel + 15%ethanol).

4. Results and Discussion

4.1. Performance Characteristics. When tested under maximum load conditions, the brake thermal efficiency (BTE) of B20E15 was found to be about 4% higher than that of pure diesel. A higher oxygen concentration in ethanol means that it will burn more efficiently, resulting in increased thermal performance. Because of the higher viscosity and resulting lower combustion rate caused by the high content of ethanol in the mix, the BTE is lower than that of B40E15 as shown in Figure 2. When compared to diesel, rubber seed biodiesel has greater viscosity and density, causing slower heat release during the first combustion phase [18]. This results in a decrease in the brake thermal efficiency. As the proportion of ethanol in the fuel mix increases, the thermal efficiency of the brakes improves. Due to the latent heat of ethanol and its high volatility, which tend to increase the blend density, the temperature of the air-fuel mixture decreases as the ethanol energy share increases. Premixed combustion is made better by the lower temperature of the

Table 1: Properties of rubber seed biodiesel and ethanol.

Sl. no	Property	Diesel	Rubber seed biodiesel	Ethanol	ASTM standards
1	Density, at 15°C (g/m^3)	0.843	0.882	0.720	D 4052
2	Viscosity, at 40°C (cSt)	2.72	5.96	1.52	D 445
3	Lowest heating value (MJ/kg)	42.31	35.82	26.92	D240
4	Flash point (°C)	60	140	13	D 93
5	Oxygen(wt%)	0	11	21	E385
6	Cetane index	54	49	8	D 613

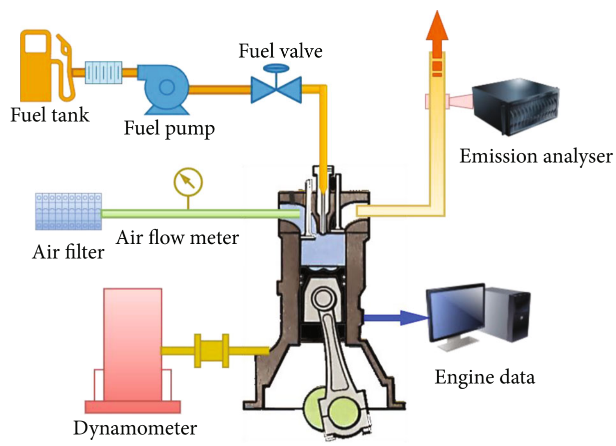

Figure 1: Experimental engine setup.

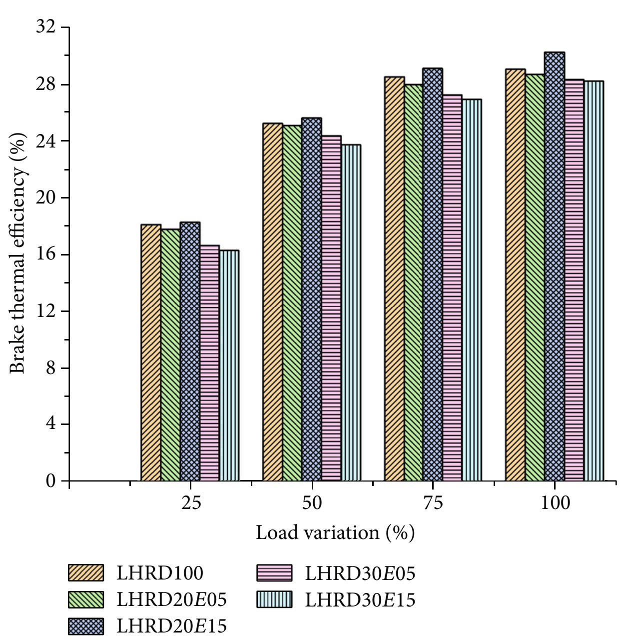

Figure 2: Variation of brake thermal efficiency with ethanol blends.

air and the longer time it takes for the fire to start because of this [1].

The thermal efficiency of the low heat rejection engine with partially stabilized zirconia coating was higher than that of the other engines because the ceramic coating acts as a heat barrier between the engine and the surrounding environment. The reduction of heat loss is allowed for an increase in engine power and thermal efficiency. [9].

Specific fuel consumption (SFC) was ascribed to the increase in injected fuel that occurred in tandem with the rise in load. The SFC decreases as the engine load increases with ethanol ratios, as shown in Figure 3. Compared to diesel, B20E05 and B20E15 blends achieved 4.6% and 13.5% lower SFC, respectively, whereas B30E15 blends achieved 8% higher fuel consumption, respectively, when compared with diesel. Because biodiesel blends have a lower calorific value and a greater density than conventional diesel, their fuel consumption is higher than that of conventional diesel while running an engine using biodiesel blends compared to traditional diesel. Fuel consumption rises as the calorific value and density of the fuel mixture decrease when the biodiesel blend ratio is increased [2].

Because of the superior heat retention qualities provided by the YSZ coating, greater in-cylinder temperatures are possible owing to better oxidation of the biodiesel mix, resulting in better atomization and vaporization, and therefore reduced fuel consumption while the engine speed is kept constant.

4.2. Emission Characteristics. When full combustion occurs at low loads, diesel emits less carbon monoxide (CO). It has lower CO emissions and more biodiesel blends than diesel. The addition of biodiesel to gasoline blends has affected CO and CO_2 emissions, the researchers found. This is because biodiesel has more oxygen. As a result, CO is reduced, and CO2 is the larger load mass, which is related to chemical processes that enhance CO production [6].

As shown in Figure 4, B20E05 and B20E15 blends decreased CO emissions by 6.8% and 9.6%, respectively, compared to pure diesel, whereas B30 blends produced higher CO emissions than diesel. The thermal barrier coatings also had an impact on CO emissions, with covered engines emitting fewer emissions than untreated engines. Nanocoated thermal insulation is activated by late-phase combustion and CO oxidation. The CO emission dropped with increasing speed, and when the engine was operating at its optimal speed, the CO emission was reduced to virtually nothing. This test also shows that CO emission is substantially controlled independent of piston coating [19].

Fuel efficiency is improved because hydrocarbon (HC) emissions are reduced, and the oxidation of atmospheric hydrocarbons is enhanced because of the oxygen present in

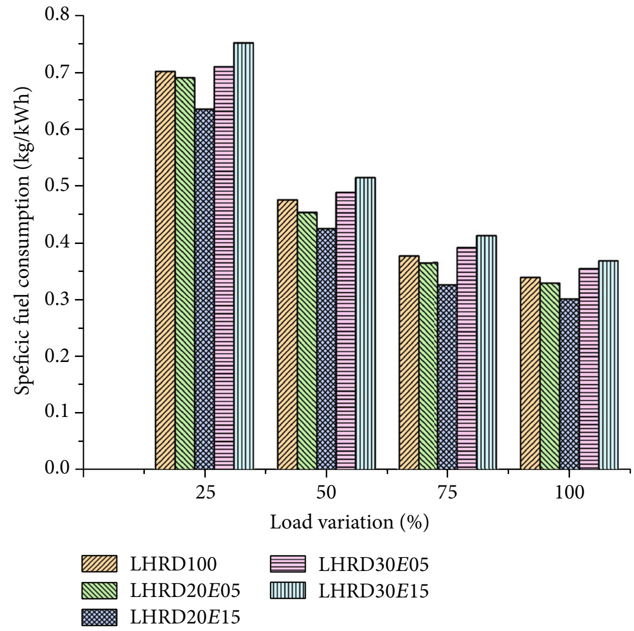

Figure 3: Variation of fuel consumption with ethanol blends.

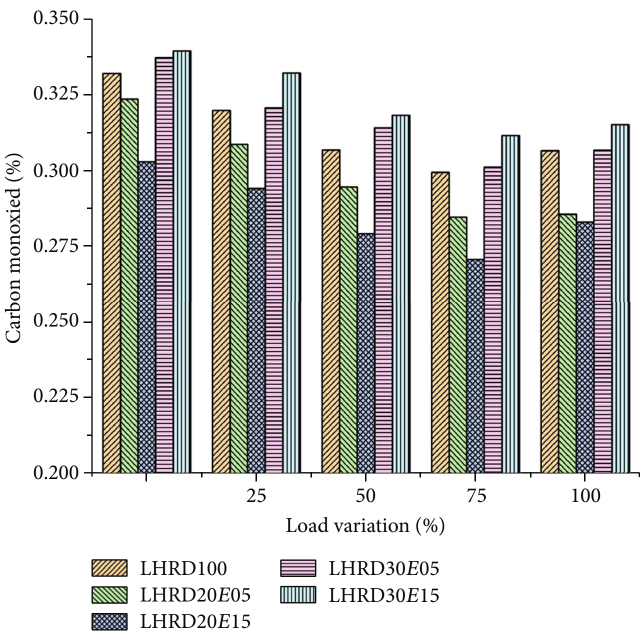

Figure 4: Variation of carbon monoxide emission with ethanol blends.

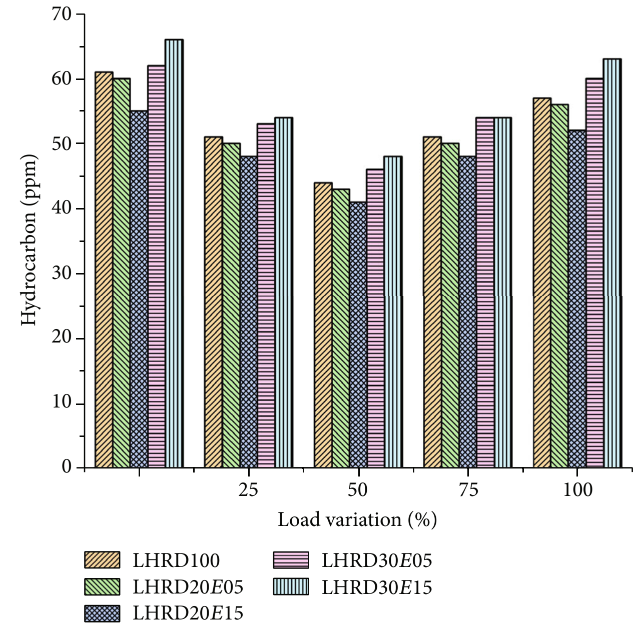

Figure 5: Variation of hydrocarbon emission with ethanol blends.

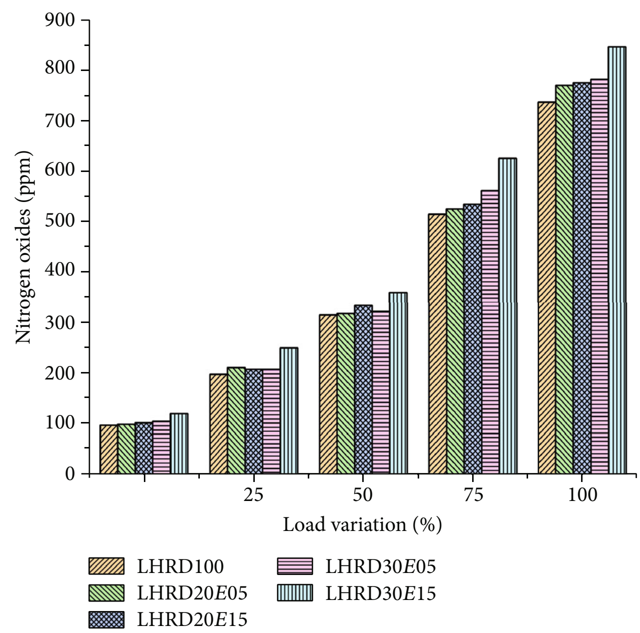

Figure 6: Variation of nitrogen oxides emission with ethanol blends.

ethanol. The higher HC emissions are caused by the lower combustion pressure and temperature achieved in ethanol combustion compared to hydrogen lead combustion, which results in less oxidation of hydrocarbons [7]. As shown in Figure 5, B20E05 and B20E15 blends reduced HC emissions by 2.5% and 8.6%, respectively, when compared to pure diesel, while B30E15 blends increased hydrocarbon emissions by 10% when compared to diesel.

A higher temperature in the combustion chamber and a coated piston crown improved fuel evaporation rates. The thermal barrier coating's greater combustion temperature facilitates and improves fuel combustion. Reduced hydrocarbon emissions were observed for coated pistons due to the thermal barrier coating's increased rate of hydrocarbon breakdown into hydrogen and oxygen in the combustion chamber. Reducing hydrocarbon emissions from heat barrier

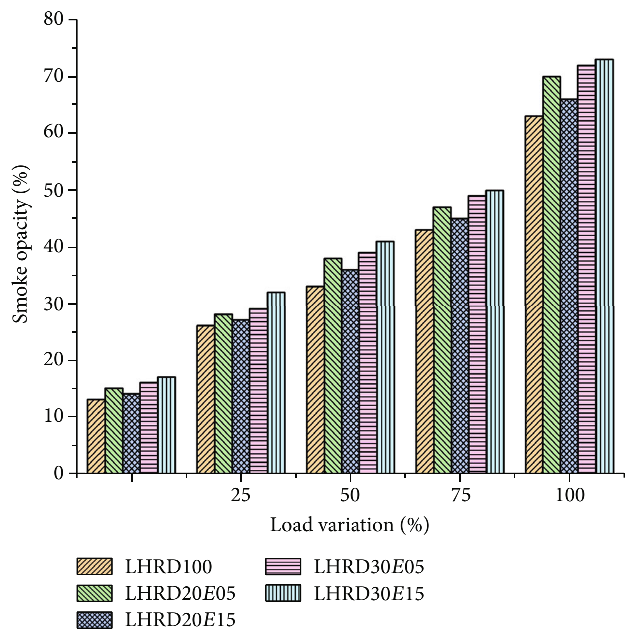

Figure 7: Variation of smoke emission with ethanol blends.

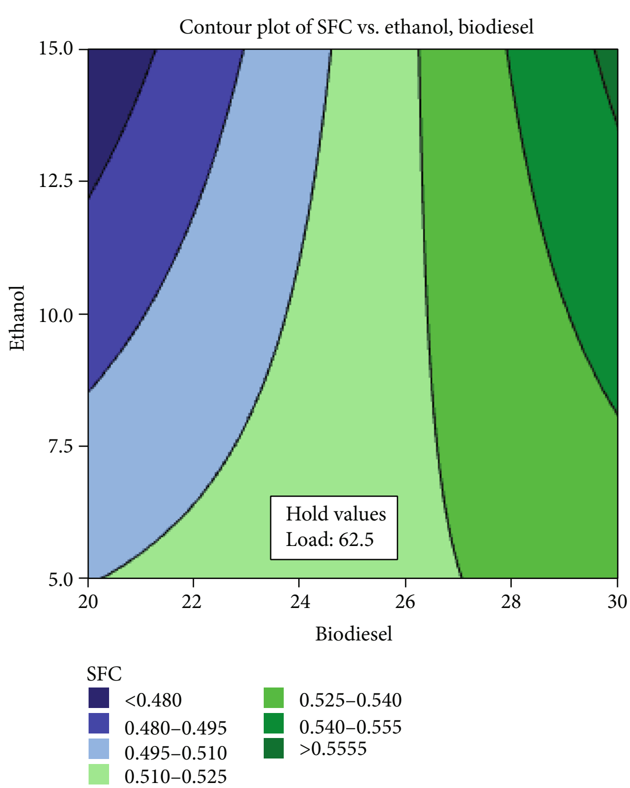

Figure 8: Influence of biodiesel and ethanol blends on SFC.

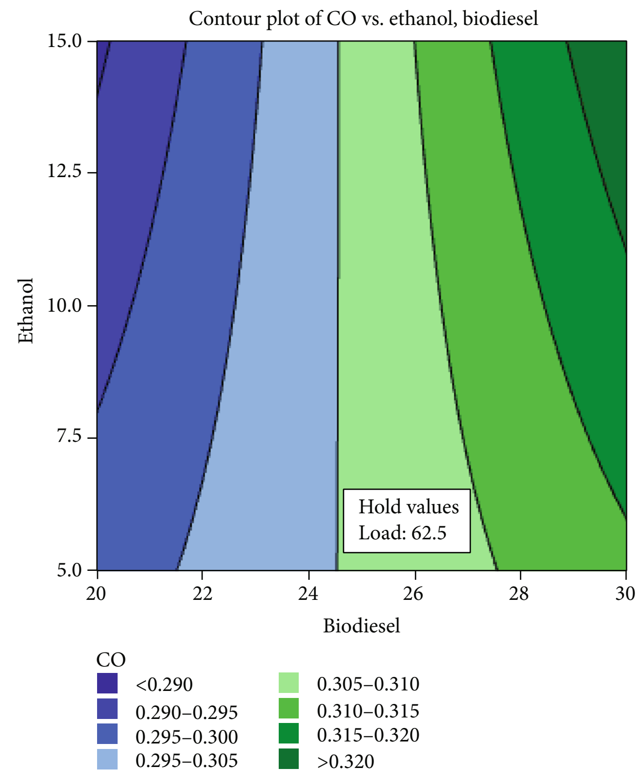

Figure 9: Influence of biodiesel and ethanol blends on CO emission.

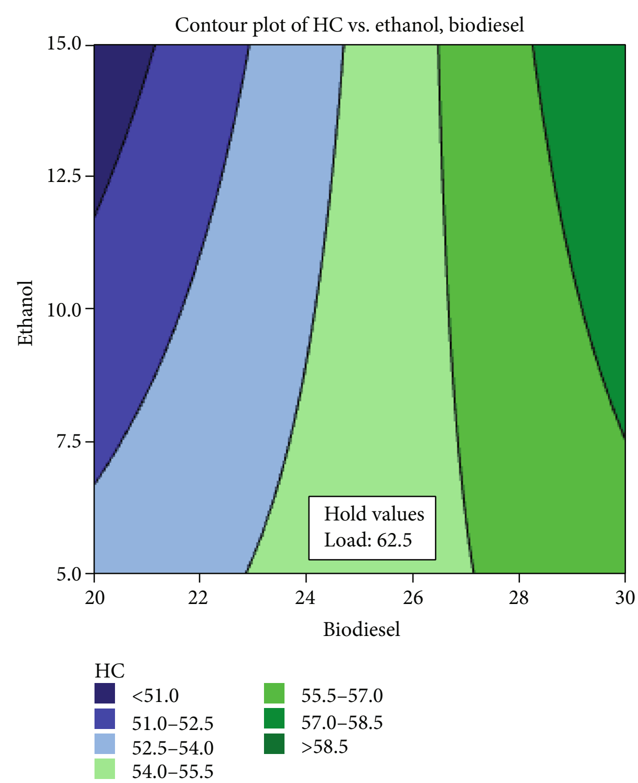

Figure 10: Influence of biodiesel and ethanol blends on CO emission.

coatings requires consideration of other aspects such as quenching distance and flammability threshold [20].

Reducing the premixed burning rate reduces nitrogen oxide (NOx) emissions while releasing heat more slowly. As ethanol's energy share rises, NOx emissions rise across the

Table 2: Parametric results on biodiesel and ethanol blends.

Solution	Load	Biodiesel	Ethanol	HCFit	SFCFit	COFit	Composite desirability
1	100.000	20.0000	15	52.0000	0.301000	0.283396	0.966458
2	99.999	20.0000	15	51.9999	0.301006	0.283396	0.966458
3	99.999	20.0000	15	51.9999	0.301006	0.283396	0.966458

board. Many factors influence NOx generation in ethanol biodiesel dual-fuel engines. As the flame temperature and burning velocity decrease, the generation of NOx is reduced [1]. As a consequence of the higher fuel use, increased engine load was blamed for the spike in NOx emissions. At maximum load conditions, B20E05, B2015, B30E05, and B30E15 blends produce NOx at a rate of 4.5%, 5.2%, 6.2%, and 14.9% greater than diesel, as shown in Figure 6.

There is just one issue with the coated engine that has to be addressed: the emission of NO. The NO emission of a coated piston engine is higher than that of a noncoated piston engine and may be higher in temperature, resulting in an earlier start of combustion that transfers pressure and temperature. Premixed biofuels are mostly burned during the premixing phase, which reduces NOx emissions [10].

The increase in the temperature of the combustion chamber and the wall temperature of the LHR engines are the two most important factors in reducing smoke. In general, nanocoating increases the proportion of pre-premixed fuel in the combustion chamber, boosts evaporation as a consequence of the very high combustion chamber temperatures, and lowers the diffusion burn, resulting in a reduction in the generation of smoke [21]. B20E05, B2015, B30E05, and B30E15 blends produce smoke at a rate of 11%, 4.8%, 14.3%, 9%, and 15.9% greater than diesel at maximum load conditions as shown in Figure 7.

The creation of smoke happens when the burning of the fuel occurs in an inefficient manner. The decrease in latent heat of vaporization and the delay in ignition that occur as the engine load increases also have an effect on the reduction in smoke emissions. When nanocoating is applied to engine components, high combustion temperatures are obtained, which has the effect of burning the fuel entirely. As a result, smoke emissions for the coated pistons at high compression ratios are decreased, as can be recorded [16].

5. Multiparametric Optimization

The design of experiment is often used in the process improvement to determine the most exhaustive solution to a solvable issue. In contrast to the conventional approach, this method makes use of statistical data acquired from a limited number of trials to forecast the understanding and repercussions of a complicated and multivariable process that is now underway. In comparison to any other research strategy, it is the most often used numerical technique for optimizing results. The number of process parameters and their levels has been needed to design a full factorial model for the research investigation. The full factorial design is a methodological and analytical process for evaluating the key effects and interactions of research projects. Even if the design is solid, giving a single element or combination of variables additional prominence results in an increase in the overall number of test points [22]. The number of process parameters and their levels were necessary for the development of a comprehensive factorial model for the study inquiry. The effect of biodiesel and ethanol blends on fuel consumption, CO, and HC emissions were examined in this study. In this research, biodiesel and ethanol blends were analyzed for their influence on fuel consumption, CO, and HC emissions.

The contour plots (Figures 8–10) demonstrate that the highest ethanol mix and the lowest biodiesel blend have the greatest impact on the engine's capacity to run at the lowest potential emissions and fuel consumption. Additionally, ethanol has a beneficial effect on fuel consumption and emissions, with the lowest values obtained at a 15% mix, which is thought to be related to a quicker combustion rate owing to the increased oxygen content. Additionally, since biodiesel has a greater viscosity, emissions rose as the mix ratio was raised, resulting in a decrease in the burning effect [23]. When a 20% biodiesel blend is utilized, the quantity of CO and HC generated is decreased because the mixture is more oxygenated, which aids in full combustion [24–26]. With an increase in the ethanol ratio, emissions fall, with the lowest amounts of carbon monoxide and hydrocarbon emissions occurring at 15% of the ethanol ratio, which is mostly due to a faster rate of combustion.

5.1. Parametric Optimization of Emission and Fuel consumption. Response optimization identifies the variables that jointly optimize a response or group of answers. This is helpful for comparing the effects of many factors on a response [27–29]. To maximize the effectiveness of response optimization, it should be understood in combination with appropriate subject matter expertise. An optimal solution for the variable input combinations is provided by the response optimizer function in statistical analysis software, as well as a visual optimization plot.

An "optimizer" is a tool that recorded the optimized results in Table 2, and Figure 11 shows that the lowest blend ratio of biodiesel at the highest ethanol additive is best for getting low exhaust emissions and the lowest fuel consumption under the most extreme conditions. This conclusion is backed up by the results. This happens because of faster combustion and a more oxygenated mixture, which leads to complete combustion at these blend ratios. The best load to get these results is when the engine is fully loaded with a B20E15 fuel blend. When the B20E15 is running at full power, the ideal CO and HC emissions are 0.283 percent and 52 ppm, and the lowest possible fuel consumption of 0.301 kg/kWh was achieved.

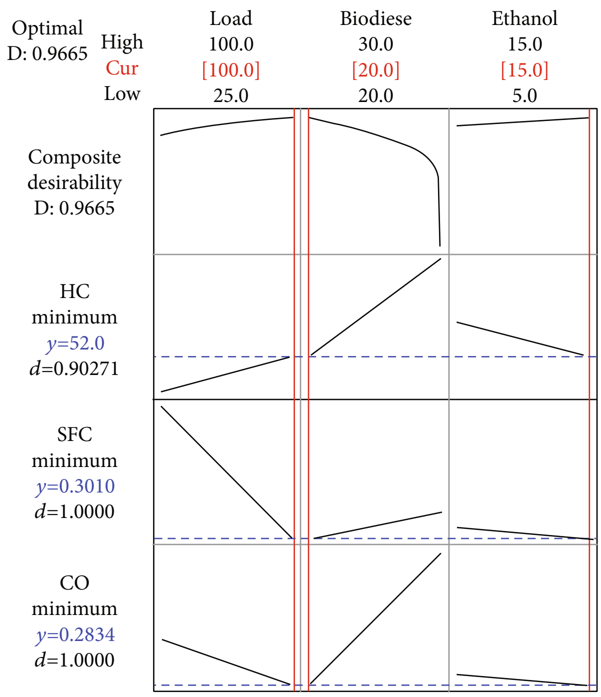

FIGURE 11: Optimization plot for emission and fuel consumption.

6. Conclusion

Diesel engines are becoming more common in developing countries like India and are used to move people and goods. This leads to more fuel use, more cars on the road, and more environmental concerns. These problems could be solved by biofuels that are made from plants and have the same properties as diesel, which could solve these problems. This study is going to look at how rubber seed biodiesel and ethanol blends work in a diesel engine. Different amounts of biodiesel and ethanol were used in a single-cylinder diesel engine with a nanocoated piston, which improves the combustion. Brake efficiency for B20E15 is about 4% better than diesel. For B20E05 and B20E15, there is a lot more oxygen in ethanol than in gasoline. This means that when comparing the specific fuel consumption of these two types of fuel, they will get about 4.6% and 13.5% less fuel consumption, respectively. CO emissions were cut by up to 6% to 8% on average with the B20 blends. At 2.5 to 8.6 percent, ethanol blends with a lot of oxygen are better for the environment than diesel because they make the combustion more efficient. When the B20E15 is running at full power, the best CO and HC emissions are 0.283 percent and 52 ppm, and the best fuel consumption is 0.301 kg/kWh.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Disclosure

This study was performed as a part of the Employment Hawassa University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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