Optimization of CI Engine Performance and Emissions Using Alcohol–Biodiesel Blends: A Regression Analysis Approach

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Abstract— The regression analysis method is used in this study work to examine the ideal engine operating parameters, including engine load, palm biodiesel content, and ethanol %. A single-cylinder, four-stroke diesel engine with various engine loads and constant speed was used for the study. Utilizing Minitab software (Version 17), a general full factorial design was created for three distinct input factors with varied values. The engine load and percentages of palm biodiesel and ethanol in ternary blends of diesel, biodiesel, and ethanol are optimized using test findings based on the regression model. At a 95% confidence level, the analysis of variance (ANOVA) showed that all three factors had a substantial impact on the performance and emission metrics. According to the regression investigation, the ideal engine load, palm biodiesel content, and ethanol share were found to be 43.43%, 11.06%, and 5%, respectively, for brake thermal efficiency (BTE), nitrogen oxide (NOx), carbon monoxide (CO), and unburned hydrocarbon (UHC) emissions. The results of this study can be applied to improve pollution and engine performance. Future studies on optimizing engine performance and emission parameters can use the regression analysis method given in this paper as a tool.

Key words: CI Engine Performance, Alcohol–Biodiesel Blends

I. INTRODUCTION

The decline in fossil fuel stocks and emission regulations have threatened the development of the modern world. Renewable fuels are growing in importance as a sustainable energy resource. Biodiesel blends with additives have been introduced to improve engine combustion. Ternary blends have shown better engine performance and lower emissions compared to biodiesel blends. Optimization of engine parameters is crucial for achieving a trade-off between performance and emissions. BTE, NOx, CO, and UHC emissions were all the subject of a non-linear regression model. ANOVA analysis is used to analyze the significant impacts of the linear, square, and interaction terms of all three components. The optimization of performance-emission characteristics was then assessed using a regression model.

II. METHODOLOGY

A. Engine Setup

A four-stroke, single-cylinder, water-cooled, direct-injection (DI) computerized diesel engine was employed in the experimental study. Figure 1 and Table 1 display the engine's schematic diagram and complete specs. To measure the engine outputs, an eddy current dynamometer was coupled to the engine crankshaft and run at a constant speed of 1500 rpm via a speed sensor. A crank angle sensor (make: Kubler) that was fixed to the crankshaft was used to measure the engine speed at each 1° crank angle. The engine was linked to a data acquisition (DAQ) system that included a computer with a crank angle encoder and Engine Soft post-processing software (Version 9.0) with a graphical user interface (GUI) Every 1° crank angle interval, the installed DAQ system was intended to measure temperature and cylinder pressure. To measure the in-cylinder gas pressure, a piezoelectric transducer was mounted atop the engine's cylinder head. Over time, all cooling water outlet and inlet temperature measurements, exhaust gas temperature (EGT) measurements, and performance data are reported. The NI Lab View centralized data acquisition system (NI USB-6210 Bus Powered M Series) interfaced with "Engine soft" software was then used to link the entire computerized system to the engine setup. A 5-gas analyzer (Make: AVL India; model: 444) equipped with a Digas sampler was used to measure the NOx, UHC, CO, CO2, and O2 in exhaust gases.

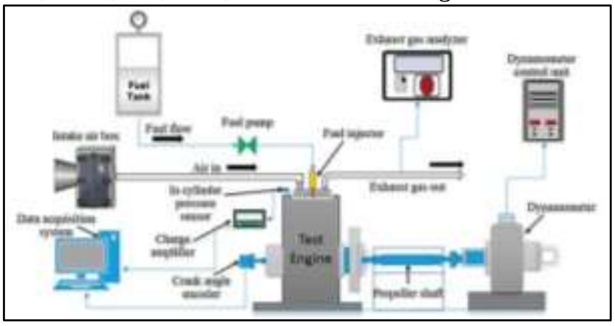

Fig. 1: Schematic diagram of the experimental engine setup.

B. Fule Preparation

Model and Engine loads ranging from 20 to 100% were used for the current experimental inquiry. In the current investigation, palm biodiesel was produced in a laboratory as illustrated in Figure, while diesel and ethanol were acquired from a local vendor. For the creation of ternary blends, various ratios of diesel, palm biodiesel, and ethanol were combined. The mix proportions of diesel, palm biodiesel, and ethanol were adjusted to range between 70 and 90%, 5 and 20%, and 5 and 10%, respectively, for the creation of various ternary blends. The quantities of diesel, palm biodiesel, and ethanol were precisely measured using a measuring cylinder for the total volume of 100%. Before starting the engine, the entire mixture was swirled to combine the mixes evenly. The mixes are represented by the notation D90B5E5, where D, B, and E stand for diesel, palm biodiesel, and ethanol, respectively. The next number displays the percentages of each fuel's volume. Table 2 is a list of the physicochemical characteristics of various blends. A gasoline burette (12.4 mm in diameter) was used to measure the fuel consumption over the course of 60 seconds. During the testing, the surrounding air's temperature and relative humidity were measured to be 27 °C and 60%, respectively. The engine was operated for 10 to 15 minutes prior to taking the reading to get it to a steady state. Engine operation was carried out for each ternary blend at 20, 40, 60, 80, and 100% load. Using the engine control panel, the load was adjusted for each unique blend from 20 to 100%. The procedure was repeated for the other blends after the engine had been set to a specific load and run for at least five minutes before reading the engine performance for 60 seconds of fuel consumption. NOx, CO, and HC emissions were measured five times for each blend under various load conditions, and their average was taken.

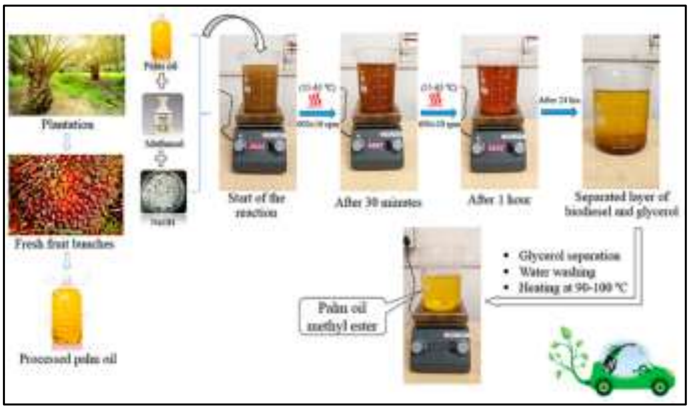

Fig. 2: Trans–esterification process of palm biodiesel preparation.

III. RESULT AND DISCUSSION

The amount of heat energy that an engine converts from fuel to mechanical power is measured by BTE. Figure 3 illustrates the changes in BTE with load, load ethanol percentage, and biodiesel percentage. Figure 3 contour plots illustrate how different amounts of ethanol and palm biodiesel affect BTE. It was shown that BTE rises as load increases and reaches its maximum at 100% load. At 100% load, a maximum BTE of 18.96% was observed with the addition of 5% ethanol and 5% biodiesel. It was found that even a small amount of ethanol and biodiesel substitution raises BTE. When more ethanol is added—from 5 to 10%—the diesel, biodiesel, and ethanol blend's overall calorific value decreases, which slows down the engine's ability to burn fuel. Figures 4, 5, and 6 display engine emissions such as NOx, CO, and UHC. Because of the ethanol and biodiesel in the ternary blend, it was discovered that NOx and UHC emissions had an increasing trend with load. The primary cause of the elevated NOx emissions is the quick rise in temperature generated during combustion at full load. Similar patterns were noted by Sathish et al. [14], who found that various ternary blends had NOx emissions that were 4.4% to 6.3% higher than baseline diesel. The majority of the carbon dioxide emissions were detected in the 0.038–0.054 vol.% range. Both ethanol and biodiesel burn more quickly when they have a high oxygen content, which reduces carbon dioxide emissions. A decrease in CO emissions as a result of the ethanol addition may be indicated by the more thorough combustion. Low CO emissions result from the blend burning more quickly due to the oxygenated properties of the ethanol and palm biodiesel.

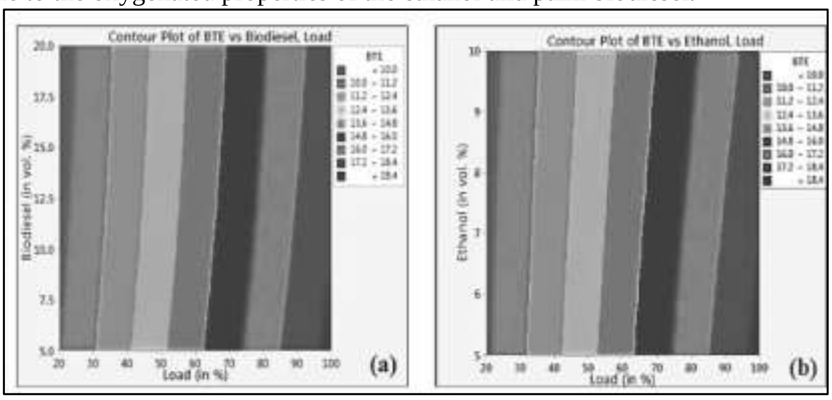

Fig. 3. (a) Contour plot of BTE vs. biodiesel, load; (b) Contour plot of BTE vs. ethanol, load

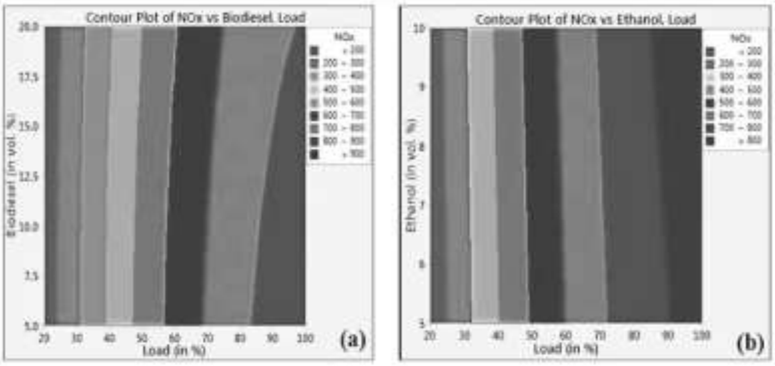

Fig. 4: (a) Contour plot of NO_x vs. biodiesel, load; (b) contour plot of NO_x vs. ethanol, load ethanol, load

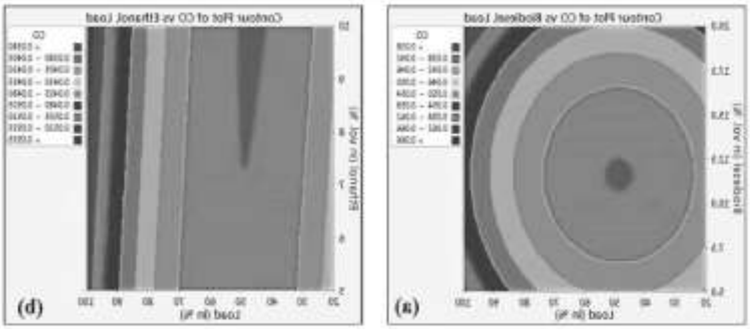

Fig. 5: (a) Contour plot of CO vs. biodiesel, load; (b) contour plot of CO vs. ethanol, load.

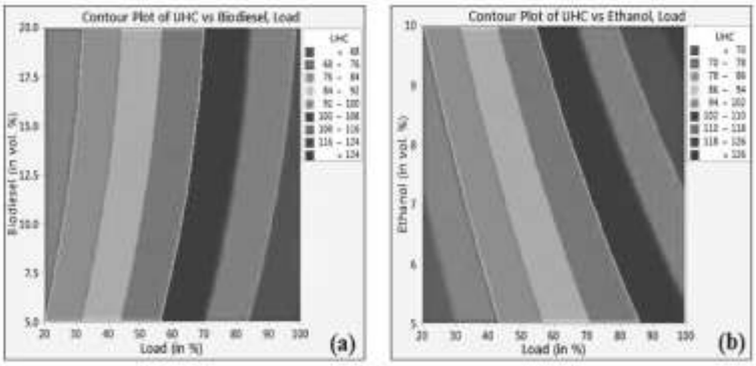

Fig. 6: (a) Contour plot of UHC vs. biodiesel, load; (b) contour plot of UHC vs. ethanol, load.

IV. CONCLUSION

This study examines the effects of varying ratios of ethanol and biodiesel in ternary blends at various engine loads. The best performance and emission characteristics of a four-stroke diesel engine were predicted using a non-linear regression model. The optimization of engine parameters was found to be significantly impacted by a number of different input factors. The results indicate that, for BTE, NOx, CO, and UHC, the optimal performance-emission parameters were 12.57%, 436.2 ppm, 0.03 vol.%, and 79.2 ppm, respectively. The optimal input parameters were 43.43% engine load, 11.1% palm biodiesel, and 5% ethanol share. Based on the previously mentioned findings, BTE-NOx-CO-UHC optimization demonstrates that ethanol and palm biodiesel have an active role in the combustion of diesel engines. By using a statistical regression model to optimize engine performance and emission parameters, this paper helps to ensure that decisions are made accurately. This method gives the decision-maker useful suggestions for furthering the study of IC engines. To achieve an optimal share of palm biodiesel and ethanol fractions in ternary blend operation, future research could examine additional operating parameters such as adjusting the compression ratio (CR), main injection pressure, timing, and duration of main injection.

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