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ORIGINAL ARTICLE

Improvement of biodiesel methanol blends performance in a variable compression ratio engine using response surface methodology

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Abstract The main objective of this work was to improve the performance of biodiesel–methanol blends in a VCR engine by using optimized engine parameters. For optimization of the engine, operational parameters such as compression ratio, fuel blend, and load are taken as factors, whereas performance parameters such as brake thermal efficiency (Bth) and brake specific fuel consumption (Bsfc) and emission parameters such as carbon monoxide (CO), unburnt hydrocarbons (HC), Nitric oxides (NOx) and smoke are taken as responses. Experimentation is carried out as per the design of experiments of the response surface methodology. Optimization of engine operational parameters is carried out using Derringers Desirability approach. From the results obtained it is inferred that the VCR engine has maximum performance and minimum emissions at 18 compression ratio, 5% fuel blend and at 9.03 kg of load. At this optimized operating conditions of the engine the responses such as brake thermal efficiency, brake specific fuel consumption, carbon monoxide, unburnt hydrocarbons, nitric oxide, and smoke are found to be 31.95%, 0.37 kg/kW h, 0.036%, 5 ppm, 531.23 ppm and 15.35% respectively. It is finally observed from the mathematical models and experimental data that biodiesel methanol blends have maximum efficiency and minimum emissions at optimized engine parameters.

1. Introduction

In light of the recent events such as decreasing fossil fuel resources, hiking crude oil price and pollution has made many researchers check the viability of biodiesels as potential alternative fuels. At this juncture a lot of research has been done on improving the efficiency of the engine by using different blends of biodiesels, using additives, advancing the injection timing, etc. All these methods have proved helpful up to some extent but the problems of low performance and emissions from biodiesels are unanswered. In this scenario, some researchers have tried to improve the performance of the engine fueled with biodiesels and their blends by using different optimization techniques. In this regard Kesign [1] investigated on the effects of operational and design parameters on

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efficiency and NOx emissions of a natural gas engine using Genetic Algorithm and neural network analysis. The results showed an increase in efficiency as well as the amount of NOx emissions being kept under the constraint value of 250 mg/Nm3 for stationary engines. Win et al. [2] studied the conflicting effects of the operating parameters (speed, load) and the injection parameter (injection timing) by varying as per $4 \times 4 \times 3$ full factorial design array on the performance like Radiated engine smoke and smoke level. The authors made some conclusions that RSM is found to be effective in obtaining objective functions between the input parameters and output parameters showing good predictions except for HC, which has a poor fit. Alonso et al. [3] studied the feasibility of using artificial neural networks (ANNs) along with genetic algorithms (GAs) to optimize the diesel engine settings to decrease fuel consumption and to regulate emissions. The authors made a conclusion that the engine emissions and consumption improvement were reached without the incorporation of any new technological device, but by just combining the operating parameters better in a way. Sayin et al. [4] studied the artificial neural network (ANN) modeling of gasoline engine to predict the brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature and exhaust gas emissions of a four-cylinder, four stroke test engine fueled with gasoline having various octane numbers (91, 93, 95, and 95.3) and operated at different engine speeds and torques. During their study the authors observed that the ANN model can predict the engine performance, exhaust emissions and exhaust gas temperature better with correlation coefficients in the range of 0.983–0.996, mean relative errors in the range of 1.41–6.66% and very low root mean square errors.

Sahoo and Das [5] in their study on optimization for biodiesel production from Jatropha, Karanja, and Polanga oils stated that the addition of biodiesel to diesel fuel changes the physico chemical properties of blends. Ganapathy et al. [6] proposed a methodology for thermodynamic model based on two-zone Weibe's heat release function to simulate Jatropha biodiesel engine performance using Taguchi's optimization approach. Using this approach, the authors concluded that the compression ratio, Weibe's heat release constants, and combustion zone duration are the critical parameters that affect the performance of the engine compared to other parameters. Najafi et al. [7] studied the performance and exhaust emissions of a gasoline engine with ethanol blended gasoline fuels using artificial neural networks (ANNs) and observed that the ANN model can predict engine performance and exhaust emissions with correlation coefficient (R) in the range of 0.97–1. Mean relative errors were in the range of 0.43–5.57%, while root mean square errors were found to be very low. Ghobadian et al. [8] studied the modeling of a two cylinder, four-stroke diesel engine fueled with waste vegetable cooking biodiesel and diesel blends and operated at different engine speeds using artificial neural networks (ANNs). Authors found the ANN model can predict the engine performance and exhaust emission quite well with correlation coefficients of (R) 0.9847, 0.999, 0.929 and 0.999 for engine torque, SFC, CO, HC, emissions. The prediction mean square error (MSE) was between the desired outputs as measured values and the simulated values were obtained as 0.0004 by the model. Jindal et al. [9] conducted experiments on the effects of the engine design parameters viz. compression ratio (CR) and fuel injection pressure.

For agricultural applications (3.5 kW), the optimum combination was found as CR of 18 with IP of 250 bar. Pandian et al. [10] investigated the effect of injection system parameters on performance and emission characteristics of a twin cylinder compression ignition direct injection fueled with pongamia biodiesel-diesel blend using response surface methodology and found that at injection pressure of 225 bar, injection timing of 21° BTDC and 2.5 mm nozzle tip protrusion were found to be optimal values for pongamia biodiesel blended diesel fuel operation in the test engine of 7.5 kW at 1500 rpm. Karnwal et al. [11] in their study on multi-response optimization of diesel engine performance parameters on Thumba biodiesel–diesel blends using Taguchi method and gray relational analysis stated that the combination of a blend consisting of 30% Thumba biodiesel (B30), a compression ratio of 14, a nozzle opening pressure of 250 bar and an injection timing of 20° produces maximum performance and minimum emissions. Costa et al. [12] in their study of CFD optimization for GDI spray model tuning and enhancement of engine performance reported that optimal choice of both the start of single injection strategy and the time of spark advance is realized by means of the simplex algorithm to maximize engine power output. Jose et al. [13] in their study of modeling and multi-objective optimization of a gasoline engine using networks and evolutionary algorithms, concluded that the non-dominated sorting genetic algorithm-II achieved reductions of at least 9.84%, 82.44%, 13.78% for CO, HC, and NOX. Molina et al. [14] experimented on the fuel consumption and NOX emissions in a diesel engine by developing a control-oriented model using Response surface methodology and found that the mean errors of predicted NOX and BSFC are 6% and 2% with a calculation time of 5.5 ms. Sivaramakrishnan and Ravikumar [15] investigated the influence of compression ratio on the performance and emissions of the diesel engine using biodiesel (10%, 20%, 30% and 50%) blended diesel fuel at compression ratios of 17.5, 17.7, 17.9 and 18.1 and the experiments were designed using the design of experiments using response surface methodology. They concluded that Desirability approach of the RSM is the simplest and most efficient optimization technique. A high desirability of 0.97 was obtained at the optimum engine parameters of CR of 17.9, fuel blend B10 and 3.18 kW power, where the values of BTHE, BSFC, CO, HC, NOX were found to be 33.65%, 0.2718 $kg/kW^{-1}\,h^{-1}$, 0.109%, 158, and 938 ppm. Hirakude and Padalkar [16] worked on the optimization of the direct injection single cylinder, diesel engine with respect to brake power, fuel economy and smoke emissions through experimental investigation and response surface methodology. Using desirability approach of the RSM, Optimization was carried out for superior performance and lesser smoke emissions and they found that a CR of 17.99, IP of 250 bar and 27° BTDC were optimal values for the Waste Fried oil Methyl Esters blended with diesel. Beatrice et al. [17] studied on the injection parameter optimization using Design of experiment on a light-duty diesel engine fueled with Bio-ethanol, rapeseed methyl ester, and diesel blend. They said that the robustness and the efficiency are enhanced by this optimization technique, and the longer ignition delay time and the lower heat content of the ethanol blend are well compensated by the closed loop combustion control. Lee and Reitz [18] studied the emission reduction capability of exhaust gas recycler and other performance parameters on a high-speed direct-injection diesel