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Optimization of engine parameters in a bio diesel engine run with honge methyl ester using response surface methodology

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ABSTRACT

In the present study an attempt has been made to optimize the engine operating parameters for the optimum thermal performance of a diesel engine fuelled with blends of honge methyl ester using the Response Surface Methodology (RSM). Design of experiments was used to plan the number of experiments. Engine experiments were carried on a water cooled diesel engine with a single cylinder connected to an eddy current dynamometer. The engine was run under varied operating conditions, such as load percentage, injection timing, blend percentage, and compression ratio. Engine responses like Brake Thermal Efficiency (BTE) and nitrogen oxides (NO_x) emissions were noted during the experiments. Response surface equations were developed to predict the values of BTE and NO_x. An ANOVA analysis was carried to observe the most significant parameters affecting the responses. It was observed that the load and the injection timing were significant for the BTE whereas the load, the injection timing, and the compression ratio strongly affect NO_x emissions. Optimization was performed using the RSM optimizer. Results indicated that when the engine was run with a load of 86.3%, using 15% blend percentage, with a compression ratio of 16, and for an injection timing of 26.24° BTDC (before top dead centre) responses obtained were found to be optimum and the corresponding values of BTE and NO_x were 31.5% and 220 ppm, respectively.

1. Introduction

The rapid depletion in the world petroleum reserves and the uncertainty in the petroleum supply have stimulated the search for alternatives to oil-based fuels, especially diesel and petrol. The majority of these petroleum fuels is being consumed by the agricultural and the transport sectors for which diesel engine passes to be the preferred prime mover. Vegetable oils have properties comparable to diesel and can be used to run a compression ignition engine with little modifications. Some of the significant properties which make vegetable oils a replacement for diesel include:

(i) Cetane numbers are in a range close to that of diesel fuel.
(ii) Heating value of vegetable oils is nearly 90% of diesel fuel.
(iii) Long chain saturated, unbranched hydrocarbons existing in vegetable oils are particularly suited for diesel engine burning.
(iv) Other benefits include it is non-toxic, contains no aromatics, has higher biodegradability than neat diesel, and makes less pollution of water and territory [1–3].

Diesel has a chain of 11–13 carbon, and the fresh vegetable oils have a chain of approximately 18. To burn in an engine, the chain needs to be broken down to be similar in length to that of the diesel. An important difference between diesel and vegetable oils is the viscosity. Vegetable oils have higher viscosity values when compared to diesel. Viscosity is important, since it affects the atomization of the fuel being injected into the engine combustion chamber. A small droplet is desired for complete combustion. A high viscosity fuel, such as a raw vegetable oil, will make a larger droplet of fuel in an engine combustion chamber which may not burn as clean as a fuel producing smaller droplets. Unburned oxidized fuel will build up around the valves, injector tips, piston side walls, and rings. Use of direct vegetable oils may lead to some problems of filter clogging and combustion chamber carbon deposits, due to their gum content, incomplete combustion characterized by nozzle choking, ring sticking, scuffing of cylinder liners, and lubricant failure due to the polymerization of the vegetable oil. Both the cloud and the pour points of vegetable oils are significantly higher than those of diesel. These high values may cause problems during cold weather. These are some of the difficulties in using pure vegetable oils in diesel engines. Heating and blending may reduce the viscosity and improve the volatility of the vegetable oils, but its molecular structure remains unchanged [4,5].

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On the basis of experimental investigations, it has been found that converting vegetable oils into simple methyl and ethyl esters is an effective way to overcome all the problems associated with vegetable oils. Such a mixture of mono alkyl esters of long chain fatty acids derived from lipid feed stock, such as vegetable oils, is called biodiesel and the process is termed as esterification [6–8]. Rao et al. [9] carried out experiments in a single cylinder diesel engine fuelled with biodiesel from Pongamia, Jathropa, and Neem seed oils. They observed the following results:

(a) Brake thermal efficiency (BTE) of B10 (10% biodiesel + 90% diesel), B20 (20% biodiesel + 80% diesel) and B40 (40% biodiesel + 60% diesel) were better than B100 (100% biodiesel), but still inferior to diesel.
(b) Smoke, hydrocarbon (HC) and carbon monoxide (CO) emissions at different loads were found to be higher for diesel, compared to B10, B20 and B40 blends
(c) Pongamia esters showed better results than Jathropa esters.

Rao et al. [10] conducted an experimental study on a single cylinder diesel engine run with biodiesel. They noticed that the BTE of the engine using biodiesel increases with the increase in blend percentage and was maximum at 20% [11]. Brake thermal efficiency was found to be lower for any further increase in blend percentage. However values of thermal efficiency were found be lower than those for diesel for all tested blend percentages. Aggarwal et al. [12] conducted an experimental study in a diesel engine run on honge methyl ester. The thermal efficiency was found to be comparable with the diesel values at all loads. Emissions of HC, CO, and smoke were reduced for engine run on biodiesel blends. NO_x emissions increased for vegetable oil esters.

Sayin et al. [13] conducted experiments using ethanol blended with diesel from 0 to 15%, with successive increments of 5% of ethanol by volume. Results showed that advancing the injection timing increased NO_x and CO_2 emissions. Advancing the injection by 6° crank angle (CA) gave the best results for HC and CO emissions (0.06% of CO and 60 ppm) when using E15 (blend of 15% of ethanol with diesel). Reducing the injection timing by 6° CA, NO_x and CO_2 emissions were found to be minimum (100 ppm and 4.15%, respectively) for the same blend. They concluded that for ethanol blends, advancing injection timings reduced CO and HC emissions, whereas retarding injection timings reduced NO_x and CO_2 emissions.

Jindal et al. [14] conducted experiments on a CI engine using Jathropa methyl ester to evaluate the effects of engine parameters, namely compression ratio and injection pressure. Experiments were conducted at three pressures of 150, 200, and 250 bar and at three different compression ratios of 16, 17, and 18 against the standard values of 210 bar and 17.5. Hence, they concluded that higher injection pressures and higher compression ratios led to better performance with marginal deterioration of some emissions, so that they recommended higher compression ratios and injection pressures than the normal settings for the biodiesel operation with Jathropa as biodiesel.

It was reported that load percentage, blend percentage, injection timing and compression ratio (CR) were the main operating parameters affecting engine operation and emissions. BTE is one of the significant performance parameters deciding the suitability of the locomotive for the different operating conditions [15,16]. It is the ratio of brake power to the heat input which indicates how efficiently the combustion has taken place, which directly influences the output power. The literature survey reveals that when diesel engines are run with the blends of vegetable oil esters, all emissions (CO, HC, and smoke) were reduced with the exception of nitrogen oxides that are very harmful to vegetation and also human life [9]. In order to meet the emission norms, specified by the government regulatory bodies, NO_x emissions have to be minimized. Further, it was noted that the parameters influencing the increase of BTE were also responsible for the increase in NO_x emissions, which is undesired. Hence, there is a need to optimize the engine operating conditions in order to have increased thermal performance (higher BTE) with reduced emissions of NO_x. Further, the optimum settings for a diesel engine run using blends of biodiesel also depends on the type of the biodiesel used.

Early prediction of responses and corresponding operating parameters will help engine designers and researchers to make the necessary changes in the design at the initial stages. Conducting extensive engine experiments for determining the optimum operating parameters for improved thermal performance is iterative and also time consuming. Combustion in an IC engine is a very complex phenomenon, wherein influencing parameters have a non-linear relationship among them. Hence, the use of analytical optimisation techniques for predicting and optimising the operating parameters and responses is cumbersome and also inefficient. This has encouraged the use of different soft computing tools for the early prediction of responses. Nataraj et al. [17] used the Taguchi method for predicting the effect of various design parameters on the diesel exhaust emission and also to optimize them. Design parameters like nozzle spray holes, nozzle protrusions, injector pressure were optimized to have lower emissions from the engine. Confirmation tests performed using optimum parameters obtained from the Taguchi method showed excellent agreement with predicted results. Desantes et al. [18] used Artificial Neural Networks (ANN) to predict and minimize $NO_x$and particulate emissions from a direct injection high speed diesel engine. They considered fuel mass, start of injection, exhaust gas recirculation (EGR), and nozzle diameter as the input variables; NO_x, particulate emission, and brake specific fuel consumption (BSFC) were used as the output variables. A back propagation algorithm was used for training the network. Results showed that R^2 (coefficient of determination) values were very close to 1, showing good relation between the input and the output variables. These results were used for parameter optimization to achieve Euro IV emission regulations. Alonso et al. [19] studied the feasibility of using ANN in combination with genetic algorithms to optimize the engine settings. The engine operating parameters were used as the input variables; BSFC together with emissions (NO_x, PM, CO, and HC) were the output parameters. The objective was to minimize specific fuel consumption simultaneously with the reduction in emissions. Best predictions were obtained for BSFC and NO_x. For CO and HC, the variance coefficient values were found to be higher, which showed poor correlation between predicted and experimental results.

The application of Genetic algorithms and Neural Networks require large number of experimental data for training the networks. Moreover, they require huge computational resources and high computational time. Training the network with fewer unplanned experimental results may lead to inaccurate predictions. As an alternative method, a planned set of engine experiments can be decided statistically by an appropriate design of experiments. These experimental results are used for prediction and optimization which can be done by using a statistical-based tool called Response Surface Methodology (RSM) [20]. Hence in the present work this novel technology was used for the prediction and optimization of engine parameters in a biodiesel engine.

RSM is one of the optimization techniques employed in many engineering problems based on the design of experiments. It helps to make a model providing a mathematical representation of the given situation for most of the statistical-based investigations. Several researchers have used RSM to investigate the influence of operation parameters on the desired end product [21–24]. Rao et al. [25] used RSM Central Composite Design (CCD) to model laser parameters when machining industrial poly vinyl chloride foams. The influence of cutting speed, laser power, frequency, and gas pressure on kerf width were investigated. The results revealed that the cutting speed is the most significant factor affecting the response, followed by the laser power. A mathematical model was developed and the predicted results were found to be very close to the experimental values. Singh [26] used RSM to optimize the machining parameters in a boring process to machine an AISI 4130 steel alloy. He carried out an ANOVA analysis to determine the most