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A Brief Review on Parametric optimization of a CRDI Engine by using DOE Method

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Abstract: *It is a well-known fact that the automotive industries have predominantly ruled the global industrial and commercial sectors. However, an increase in the demand for fossil fuels and stringent emission norms have paved a way for alternative fuels in IC engines, certain optimization protocols are followed by the automotive industry to save the time and cost involved in production, design and engine operating conditions. However, due to the broad nature of this subject in automotive applications, the optimizations of engine operating conditions and their respective parameters are deeply delved into in this article. In order to guide novice engine researchers, this article intents to critically elucidate the Taguchi optimization techniques used by researchers for improving the performance of spark ignition, compression ignition engines, CRDI engines systems and its various sub-systems. This article begins with the need of biodiesel in todays' era, need of biodiesel operating parameters optimization, introduction about the Taguchi technique for optimization, stepwise procedure for implementing the Taguchi's optimization technique, literature survey on experiments done by the different researchers in this area, and detailed case study on the research work done by different researchers to understand the methodology accepted and to understand the experimental results and graphs so that we can continue the same research with different new options and prepare the experimental design plan approach for screening and optimization of multi point optimization of Taguchi approach. From the review, it can be concluded that the Taguchi technique efficiently assists in exploring the in-depth engine function relation between the input variables.*

Keywords: Biodiesel**,** CRDI Engine, Parametric optimization, Performance Characteristics, Taguchi Method

I. INTRODUCTION

Diesel engine-based technology in the present millennium has undergone a paradigm shift in its perspectives to meet the increasingly stricter emission directives on one hand and consumer expectations of superior fuel economy on the other. Such a state of responsiveness to the present day requirements is necessitating an unprecedented increase of dependence on control of the several new degrees of freedom that are being called into play simultaneously by virtue of the significant increases in the mechanical and electronic complexity of engine hardware and after treatment systems dictated by the incorporation of new technologies such as VVT, VGT, CRDI, GDI, VIS, exhaust after-treatment add-ons of SCR, DPF etc. together with the shift towards newer and innovative low temperature combustion technology concepts such as HCCI (Homogeneous Charge Compression Ignition), DCCS (Dilution Controlled Combustion System), HPLI (Highly Premixed Late Injection), HCLI (Homogeneous Charge Late Injection), Premixed Charge Compression Ignition (PCCI) and Reactivity Controlled Compression Ignition (RCCI) offer the promise of improved engine efficiencies along with markedly reduced emission footprints from conventional engines. Common Rail Diesel Injection systems have led the technological renaissance in diesel injection characteristics of the present day due to its efficacy in drastically reducing BSFC and the conventional PM emission precursors as compared to conventional diesel operation. That said the very ability of the CRDI systems to decrease PM emissions has been found to be a penalizing precursor for NOx formation which have been observed to paradoxically increase on account of higher peak

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temperature arising out of very lean and homogenous conditions which provide impetus for attaining close-to adiabatic flame temperatures during the ensuing combustion. To contain the consequence of NOx emissions while retaining the incentives of lower PM and fuel consumption on CRDI systems, EGR and pilot injection strategies have been widely investigated. Comparing the context of the present day insecurities of convention fossil fuel based energy resources, air pollution, and climate change that are collectively calling into question the fundamental sustainability of the current energy system, alternative fuels, are destined to be a dominant stake holder in the transition of the energy sector in the immediate future. It is thus apparent from the discussion that the PM-NOx-BSFC trade-off problem requires increased design space to explore the possibility of obtaining possible solutions to satisfy the conflicting objectives. Such extended design space is provided by the increase in control/design variables which can be suitably explored for attaining the desired objectives. Though a full factorial approach would have been the ideal methodology to explore the entire design space with one at a time variation of the input variables, such efforts are constrained by the penalty of unviable experimental cost and time. Thus, a methodology is needed to be adopted wherein the optimal exploration of the design space can be performed with reduced yet experimentation. To this end the Taguchi methodology provides an effective and established statistical tool derived from the theory of design of experimentation. Though, the Taguchi platform has been utilized as a very popular process optimization technique, it has been observed to be unsuitable to solve multi-objective optimization problems (MOOPs). To overcome this limitation, grey relation analysis (GRA) theory need to be employed in conjunction with the Taguchi method.

II. BRIEF REVIEW

K. Sivaramakrishnan et al., [1] performed an experiment on performance optimization of Karanja biodiesel engine using Taguchi approach and multiple regressions. The objective of this work was to optimize the direct injection (DI) single cylinder diesel engine with respect to brake power, fuel economy and emissions through experimental investigations and DOE methods. A single cylinder 5.2 kW diesel engine was selected for test. Five parameters, Power (P), Static injection pressure (IP), Injection timing (IT), Fuel fraction (B) and Compression ratio (CR) was varied at four levels and the responses brake power, fuel economy and emissions were investigated. The optimum values of the response was predicted using Signal - Noise ratio(S/N ratio) and optimum combination of control parameters were specified. The best results for brake specific fuel consumption (BSFC), brake thermal efficiency (BTHE) were observed at increased CR, IP, and IT. The emissions CO, HC were reduced while NOx emissions increase. The results of the study revealed that the combination of a blend of 30% karanja biodiesel (B30), a compression ratio of 17.9, a nozzle opening pressure of 230 bar, injection timing of 27° bTDC and at 70% load i.e., 3.64 kW produces maximum multiple performance of diesel engine with minimum emissions from the engine.

Goutam Pohit et al.,[2] performed an experiment on optimization of performance and emission characteristics of diesel engine with biodiesel using Grey-Taguchi Method. In this experiment they studied, the effect of Karanja oil methyl ester diesel fuel blends (B 0, B 25, B 50, B 75, B 100) on engine performance and exhaust emissions were investigated. The engine performance and emission characteristics had been analyzed in the context of applicability of blend of Karanja oil methyl ester with conventional diesel as a suitable alternative fuel resource. In the study, an attempt was made to optimize the engine responses comprising of eight different parameters when three input parameters were varied simultaneously. Design of experiment was carried out using Taguchi method to limit the number of experiments by the formation of orthogonal array. Subsequently, multi response problem was converted into a single one with the application of weighting factors of grey relational analysis and optimum solution was obtained from the test data. Finally finding of experimental study was validated with the result obtained through actual experimentation. It was concluded that B 50 blend was found to be most suitable blend for diesel engine without significantly affecting the engine performance and emissions characteristics, corresponding compression ratio and engine load being 17 and 80% respectively.

Maulik A Modi et al., [3] performed an experiment on parametric optimization of single cylinder diesel engine for palm seed oil & diesel blend for brake thermal efficiency using Taguchi method. In this experiment they studied the effects of parameters` i.e. load, compression ratio and injection pressure are taken as variable for optimization. Taguchi method of optimization is used in this experiment. The results of the Taguchi experiment identify that 16 compression ratio, injection pressure 180 bar and engine load 10kg are optimum parameter setting for highest brake thermal efficiency. Engine performance is mostly influenced by engine load and is least influenced by compression ratio. Confirmation experiment was done using an optimum combination showed that the brake thermal efficiency was found by experiment is closer to the predicted value. The Taguchi method was found to be an efficient technique for quantifying the effect of control parameters.

Dhruv V. Patel et al., [4] performed an experiment on Parametric Optimization of Single Cylinder Diesel Engine for Jatropha Biodiesel and Diesel Blend for Mechanical Efficiency Using Taguchi Method. In this experiment, the feasibility of using taguchi method to optimize selected diesel engine parameter for highest performance was investigated using single cylinder, 4-stroke diesel engine. From this work, they concluded as follows : 1) The taguchi method was found to be an efficient technique for quantifying the effect of control parameter. 2) The highest performance at set 50% blend ratio, engine load 10kg, and compression ratio 16, which are optimum parameter setting for highest mechanical efficiency. 3) Engine performance is mostly influenced by engine load and is least influenced by blend ratio. 4) Performance results obtained from the confirmation experiment using optimum combination showed excellent agreement with the predicated result.

Xiaoxiao Niu et al., [5] done study on Investigation of ANN and SVM based on limited samples for performance and emissions prediction of a CRDI-assisted marine diesel engine. In this experiment, they have investigated the performances of Artificial Neural Network (ANN) and Support Vector Method (SVM) approaches for the responses prediction of a common rail direct injection system (CRDI)-assisted marine diesel engine. The Taguchi orthogonal array is employed for the operating points determination of training data; then, based on the same training data, which contain only 25 samples, the predictive performances of ANN and SVM are evaluated and compared. The comparison of ANN and SVM indicates that with limited experimental data, SVM can find the optimal global solution and has excellent predictive accuracy and generalization capability, while ANN may converge to local minima and face the overfitting problem. The major conclusions are as follows: 1. Based on limited training samples, the evaluation of ANN predictive performance shows that the predictive accuracy of ANN is unstable with the change of the number of neurons in the hidden layer and the random initial weights and threshold values. By contrast, SVM has a quite stable performance. 2. The comparison of ANN and SVM indicates that with limited experimental data, SVM can find the global solution during the training process and has excellent predictive accuracy and generalization capability, while ANN may converge to local minima and could face the overfitting problem. Eventually, this study suggests that SVM is well-suited for application to diesel engine response predictions and will reduce the experimental cost significantly.

Amit. R. Patil et al., [6] had done experiment on Parametric optimization of engine performance and emission for various n-butanol blends at different operating parameter condition. In this experiment, study of effect of different n-butanol diesel blends (5–20% v/v) on engine performance and emission were performed for different engine operating parameter. Optimization was carried out with help of Taguchi DoE method. Single Cylinder VCR Compression Ignition Engine was used for the experiment and tested at different engine settings of CR, FIP and FIT for different load conditions. Normality analysis was performed to check the distribution of response data and then regression analysis was performed to derive the mathematical model for the chosen responses (BSFC, BTE, NOx and Smoke) based on n-butanol and engine parameters. During the optimization analysis, it is found that n-butanol of 15% concentration in diesel with engine settings, CR of 15, FIP of 260 bar and FIT of 250 bTDC give optimize BTE, BSFC and low smoke but resulted in higher NOx formation. The use of 15%v/v of n-butanol was found to be most suitable blend proportion with diesel as it resulted in favorable engine performance and low emission for all test load conditions. Also, it was observed that Taguchi method is highly effective when individual response parameter need to be optimized for different engine responses and to identify the significant factor from multiple design factors. But for optimization of multiple design factors for most favorable responses, use of advanced optimization methods to be implemented.

T. Sathish Kumar et al., [7] had done the review on Application of statistical approaches in IC engine calibration to enhance the performance and emission Characteristics: A methodological review.. In order to guide the novice engine researchers, this article intents to critically elucidate the optimization techniques used by researchers for improving the performance of spark ignition and compression ignition engines systems and its various sub-systems. Initially, this article begins with experimental design plan approach for screening and optimization. Then elucidate about the single

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point optimization of Taguchi approach and multi-objective optimization of RSM approach. Further, provides the information of predictive optimization approach of Genetic algorithm in engine optimization and artificial neural networks for recognize the engine behavior pattern. Moreover, this article also explains the certain methods to analyze the accuracy and model-fit significance for certain methodologies using an experimental case study dedicated solely for this article. From the review, they have concluded that the statistical technique efficiently assists in exploring the in-depth engine function relation between the input variables.

Sudarshan Gowrishankar et al., [8] had done experimental Investigations on Parametric optimization with Biodiesel-water emulsion under premixed lean combustion to achieve high efficiency and clean combustion. The present investigation envisages combining renewable biodiesel-water emulsions and an advanced premixed lean combustion strategy to curtail the higher HC and CO emissions without sacrificing engine performance. Non-edible Karanja oil was the source of biodiesel and the emulsion stabilizer. The engine operating parameters were optimized, including fuel injection timing, EGR flow rate, and emulsion water concentration. Emulsions of neat biodiesel were prepared to contain 6, 12, and 18% water on a mass basis using 1 and 2% surfactant by mass. The fuel injection timing was varied from 2 to 4 degrees after the top dead center, and up to 15% EGR flow rate was utilized. Design of experiments aided in minimizing the number of engine tests. The performance and emission parameters were the output responses. Taguchi Grey Relational Analysis established the optimal combination of input factors to improve engine performance and reduce exhaust emissions. Engine experiments at optimized operating conditions revealed that compared to conventional diesel combustion, the brake thermal efficiency and brake specific fuel consumption improved by 33 and 16%, respectively, at 5.08 bar BMEP. The NOx, smoke and HC emissions were reduced by 68, 73 and 46%, while CO emissions increased nearly two-fold.

Sumit Roy et al., [9] had done experiment on Application of Grey-Taguchi based multi-objective optimization strategy to calibrate the PM-NHC-BSFC trade-off characteristics of a CRDI assisted CNG dual-fuel engine. This work attempts to simultaneously reduce the BSFCeq, NHC and PM emissions of a CRDI assisted diesel engine under CNG-diesel dual-fuel mode. Load, fuel injection pressure and CNG energy share were chosen as input parameters with NHC, PM and BSFCeq as the response variables. To reduce the experimental effort the experiments have been performed by employing Taguchi's L16 orthogonal array. In order to search for the optimal process response, the Grey relational analysis is employed for solving the optimization problem. The optimal combination of the input parameters was obtained using the Grey relational grade and signal-to-noise ratio as a performance index, which achieved the desired response characteristics. The following conclusions were drawn based on the above analysis: 1. The investigation shows that the optimal combination of the input parameters is 4 kg load, 540 bar FIP at 15% CES. 2. Load was found to be the most influencing factor for the chosen objective to reduce NHC with less effect on PM and BSFCeq. 3. The confirmation result reveals that the method is suitable for optimizing the performance and emission parameters of an IC engine. The optimal combination so obtained was further confirmed through experimentation. Among the three, load was found to be the most influencing factor.

Jayaprabakar Jayaraman et al., [10] had done an experiment on Artificial intelligent-based analysis of VCR engine with biodiesel blends and modelling using uncertainty techniques. In this experiment, Taguchi method was used to optimize the parameters. Three factors, three level performance matrix, were considered in order to carry out the experimental investigation. Performance found better for 18:1, no deviation in volumetric efficiency, The impact of the inputs on output values are considerable and change in load have 1.3% to 3.3% influence when compare with CR of 1.02% to 1.15% and blend proportions in the range of 1% to 1.5%.

Pajarla Saiteja et al., [11] performed an experiment on Study on interactive effects of CRDi engine operating parameters through RSM based multi-objective optimization technique for biofuel application. In this work, optimization of D+LPO (20% waste-based lemon peel oil and 80% diesel) fueled Common Rail Direct Injection (CRDi) engine fuel injection parameters for the optimum performance and emission characteristics done. The parameters such as Injection Pressure (IP), Dwell Time (DT), Pilot Mass (PM) and Pilot Timing (PT) are considered to enhance the performance and decrease the emissions. In this work, it was observed that, D+LPO blend at IP 700 bar, PM 20%, PT 27bTDC and 12 DT was predicted to be an optimum operating condition for this particular engine.

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K. Sivaramakrishnan et al., [12] performed an experiment on performance optimization of karanja biodiesel engine using Taguchi approach and multiple regressions. The basic objective was to optimize brake power, fuel economy and emissions through experimental investigations and DOE methods. Five parameters, Power (P), Static injection pressure (IP), Injection timing (IT), Fuel fraction (B) and Compression ratio (CR) was varied at four levels and the responses brake power, fuel economy and emissions were investigated. The results of the study revealed that the combination of a blend of 30% karanja biodiesel (B30), a compression ratio of 17.9, a nozzle opening pressure of 230 bar, injection timing of 27° bTDC and at 70% load produces maximum multiple performance of diesel engine with minimum emissions from the engine.

Goutam Pohit et al., [13] performed an experiment on Optimization of Performance and Emission Characteristics of Diesel Engine with Biodiesel Using Grey-Taguchi Method. The objective was to determine the optimum blend of Karanja biodiesel and diesel on engine performance and emission characteristics of a VCR. Input parameters, namely, load (A), blend of fuels (B), and compression ratio (C) were considered into five levels each. Performance characteristics of the engine, namely, BP, BSFC and brake BTE and emission characteristics of the engine, namely, CO, CO2, O2, NOx, and HC. The optimized parameters were B 50 blend, CR 17 and 80% load.

Maulik A Modi et al., [14] performed an experiment on Parametric Optimization Of Single Cylinder Diesel Engine For Palm Seed Oil & Diesel Blend For Brake Thermal Efficiency Using Taguchi Method. In this study, the effects of parameters` i.e. load, compression ratio and injection pressure are taken at three levels as variable for optimization. The optimum results of the experiment identify that 16 compression ratio, injection pressure 180 bar and engine load 10kg are optimum parameter setting for highest brake thermal efficiency.

Dhruv V. Patel et al., [15] performed an experiment on Parametric Optimization of Single Cylinder Diesel Engine for Jatropha Biodiesel and Diesel Blend for Mechanical Efficiency Using Taguchi Method. In this study, the effects of parameters' i.e. load, blend proportion and compression ratio are taken as variable for optimization. The results of the taguchi experiment identifies that 50% blend ratio, compression ratio 16 and engine load 10kg are optimum parameter setting for highest mechanical efficiency.

B. Venkatanarayana et al., [16] performed an experiment on Selection of optimal performance parameters of DI diesel engine using Taguchi approach. In this study, input factors such as load, percentage of Karanja oil methyl ester (KOME) blend, compression ratio (CR), injection pressure (IP) and injection timing (IT) were considered in order to evaluate the brake specific fuel consumption (BSFC) and exhaust emissions such as carbon monoxide (CO) and smoke using Signal to noise ratio(S/N) and Analysis of variance (ANOVA). It was found that the CR has the most significant influence on the BSFC; CO exhaust emission was most influenced by load, followed by IP and IT; and smoke opacity was highly influenced by IT.

Suresh Vellaiyan et al., [17] performed an experiment on Multi-response optimization to obtain better performance and emission level in a diesel engine fueled with water-biodiesel emulsion fuel and nanoadditive. In this study, the diesel engine is fueled with different concentrations of soybean biodiesel (SB), water, and alumina (Al) nanoadditive. Taguchi method coupled with gray relational analysis has been implemented in this study to obtain the optimum concentration of SB, water, and Al nanoparticle. From the obtained gray relational co-efficient (GRC) and signal-to-noise (S/N) ratio, the optimum concentration of SB, water, and nanoadditive are identified as 20%, 10%, and 100 ppm, respectively.

S. Ganesan et al., [18] performed an experiment on Optimization of CI Engine Parameter Using Blends of Bio-Diesel by Taguchi Method. In this study, In this experimental, different blend of biodiesel is tested at different compression ratio and the multi-response parameters (engine performance and emission study) are optimized using grey relational analysis and converted into a single response. The optimized result was compression ratio of 14 and the B.P applied on the engine is 4.4 kw.

Naushad Ahamad Ansari et al., [19] performed an experiment on performance and emission analysis of a diesel engine implementing polanga biodiesel and optimization using Taguchi method. In the study, the effect of polanga blends on fuel injection timing and fuel injection pressure is considered as input factors to examine engine output parameters and minimum exhaust emission. In the study, the optimal values of BTE, UHC, NOx, and smoke emissions obtained are 32.59%, 20.3 ppm volume, 551 ppm volume, and 94.2 % respectively at 30 % polanga biodiesel blend with 15o bTDC fuel injection timing and 200 bar injection pressure.

Naushad Ahamad Ansari et al., [20] performed an experiment on performance and emission analysis of a diesel engine implementing polanga biodiesel and optimization using Taguchi method. In the study, the effect of polanga blends on fuel injection timing and fuel injection pressure is considered as input factors to examine engine output parameters and minimum exhaust emission. In the study, the optimal values of BTE, UHC, NOx, and smoke emissions obtained are 32.59%, 20.3 ppm volume, 551 ppm volume, and 94.2 % respectively at 30 % polanga biodiesel blend with 15o bTDC fuel injection timing and 200 bar injection pressure.

M. Gul et al., [21] performed an experiment on Grey-Taguchi and ANN based optimization of a better performing low-emission diesel engine fueled with biodiesel. In the study, optimum combination of nature of fuel, speed of engine, and load for DI- CI diesel engine fueled with waste cooking oil (WCO) based pure biodiesel (B100) & 20% blend of biodiesel with neat diesel (B20) with an objective to achieve maximum reduction in smoke and NOx emissions and to enhance the output parameters like engine's heat release, cylinder pressure and brake power and of brake specific fuel consumption of the engine at various load conditions. The optimal input parameters were, nature of fuel as B100, speed as 2300 rpm and load as 100%.

Vezir Ayhan et al., [22] performed an experiment on Optimization of the factors affecting performance and emissions in a diesel engine using biodiesel and EGR with Taguchi method. In this study, using different proportions of corn oil methyl ester (COME) blends (B0, B10, B20 and B50) and EGR (EGR0, EGR10, EGR15 and EGR20) on a direct injection (DI) diesel engine at variable loads (40%, 60%, 80% and 100%) and speed (1600 and 2400 rpm) conditions, the optimum factor levels in terms of performance and emission characteristics were determined by Taguchi method. The optimum results for power were at full load condition, in B20 fuel, without EGR at 2400 rpm. The optimum results for SFC and effective efficiency were at 80% load, B10 fuel, EGR and 1600 rpm. The best results for NO emissions were at 40% partial load, B0-diesel fuel, 20% EGR ratio and 2400 rpm. The best results for smoke emissions were at 40% partial load, B10 fuel, without EGR at 1600 rpm. The optimum values of HC and CO emissions were 40% partial load, B50 fuel, no EGR and 1600 rpm. The optimum values of CO2 emissions were at 40% partial load, diesel fuel, no EGR applied and 1600 rpm.

S. Saravanan et al., [23] performed an experiment on Effect of design parameters on performance and emissions of a CI engine operated with diesel-biodiesel- higher alcohol blends. This study attempts to study the influences of piston geometry, butanol fumigation, EGR, injection pressure and injection timing upon the performance and emissions of a light-duty DI diesel engine fuelled with diesel, Jatropha methyl ester (JME) and 20% by vol. of n-butanol/diesel blends. Taguchi method is used for optimization of input parameters for NOx emission, smoke opacity and BSFC as output parameters. Results indicated that B20 injected at 20oCA bTDC with an injection pressure of 200 bar under 10% EGR alongside 40% by vol. of butanol/diesel fumigation with a premixing ratio of 20% at 9oCA aTDC in the engine fitted with a torroidal piston.

Sureshbabu Yessian et al., [24] performed an experiment on Optimization of Performance and Emission Characteristics of Catalytic Coated IC Engine with Biodiesel Using Grey-Taguchi Method. In this investigation cotton seed oil is used as a bio- diesel and the piston and combustion chamber were coated with copper chromium zirconium material with a thickness of 250 microns. The main contributing factors for improving performance such as load, fuel and speed have been preferred to reduce the emission and improve the performance of an IC engine. Design of experiment by Taguchi with grey relational analysis optimization (GRA) method is used, for improving the IC engine performance and reducing the emissions. The result shows modified copper chromium zirconium (CuCr1Zr) catalytic coated piston produces less emission and improves performance when compared to standard un-coated piston type engine.

Amit. R. Patil et al., [25] performed an experiment on Parametric optimization of engine performance and emission for various n-butanol blends at different operating parameter condition. In this study, effect of different n-butanol diesel blends (5–20% v/v) on engine performance and emission were performed for different engine operating parameter. Optimization was carried out with help of Taguchi DoE method. Single Cylinder VCR C.I Engine was fuelled with different blend of diesel and n-butanol and tested at different engine settings of CR, FIP and FIT for different load conditions. During optimization analysis, it is found that n-butanol of 15% concentration in diesel with engine settings, CR of 15, FIP of 260 bar and FIT of 25obTDC give optimize BTE, BSFC and low smoke but resulted in higher Nox.

Samet Uslu et al., [26] performed an experiment on Effect of operating parameters on performance and emissions of a diesel engine fueled with ternary blends of palm oil biodiesel/diethyl ether/diesel by Taguchi method. In this paper, test were planned based on Taguchi L27 orthogonal array (OA) that considered DEE ratio, palm oil ratio, injection advance and engine load as factors and brake BTE, BSFC, exhaust gas temperature (EGT), carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NOx) and smoke emissions as responses. The highest signal-to-noise (S/N) ratios of BTE, BSFC and EGT were observed with the low DEE ratios, low injection advance values and average engine load. Overall, the highest S/N ratios achieved for emission responses were obtained with high DEE percentages and 35 CAs. While the highest S/N ratios for CO and smoke were seen with 20% palm oil, the highest S/N ratios were obtained with 0% palm oil for all other responses.

Abhishek Sharma et al., [27] performed an experiment on Effect of design parameters on performance and emissions of DI diesel engine running on biodiesel-diesel blends: Taguchi and utility theory. This study focused on the optimization of a diesel engine operating parameters fuelled with pongamia biodiesel blend at full load. The optimization was carried out for different input parameters including pongamia biodiesel blends (0–40%), fuel injection timing (15–31) °bTDC, and fuel injection pressure (16–24) MPa. Optimized result was, pongamia biodiesel (10%) with injection timing 23°bTDC and injection pressure 22 MPa found the best input engine setting at full engine load.

Ranjeet Kumar Rai et al., [28] performed an experiment on Taguchi-Grey method optimization of VCR engine performance and heat losses by using Shorea robusta biodiesel fuel. In this experiment, diesel based Shorea robusta biodiesel blends of SRME10, SRME20, SRME30, and SRME 40 were prepared, and its effect on the performance characteristics, emission attributes, and heat losses for the VCR engine were investigated using Taguchi method. Compression ratio, load, and % blends of fuel with four levels of each were taken as control parameters to optimize the response characteristics, i.e., BMEP, BSFC, volumetric efficiency (ηv), water heat loss (HJW), exhaust gas heat loss (HJGAS), NOx, HC and CO emissions. Experimental investigation and optimization analysis revealed that a compression ratio of 17, a load of 10 kg, and fuel blend of SRME30 were the optimum results for the performance and heat losses.

Krishna Shrivastava et al., [29] performed an experiment on Optimization of diesel engine performance and emission parameters of Karanja biodiesel-ethanol-diesel blends at optimized operating conditions. In this experiment, four input parameters as Injection angle, Compression ratio, Blend % and loads varied to obtain engine responses as Brake thermal efficiency, Brake specific fuel consumption, Exhaust gas temperature, Carbon dioxide, Carbon monoxide, Nitrogen Oxide and hydrocarbon using Taguchi method. Further single combination of input parameters for all seven responses as Injection Angle 19◦CA bTDC, Compression ratio 18, Krishna 30 (fuel blend) and 50% load was obtained by Gray Relational Analysis.

Praveen Ramesh et al., [30] performed an experiment on Performance optimization of an engine for canola oil blended diesel with Al2O3 nanoparticles through single and multi-objective optimization techniques. In this experiment, diesel engine is fueled with canola oil blended diesel with aluminium oxide nanoparticles. Taguchi's signal to noise (S/N) ratio method, grey relational method, and response surface method are employed to maximize the brake thermal efficiency (BTE) and minimize the nitrogen oxide (NOx) emissions and fuel cost. The optimum values are identified as Canola oil blend percentage = 18.8%, concentration of nanoparticles = 30 ppm, fuel injection pressure = 220 bar and fuel injection timing = 21◦ before top dead center (bTDC) and this combination improve BTE by 16% and reduce the NOx by 3% with reference to diesel fuel.

Suleyman Simsek et al., [31] performed an experiment on Multi-objective-optimization of process parameters of diesel engine fueled with biodiesel/2-ethylhexyl nitrate by using Taguchi method. In this investigation, the effects of fuel mixtures prepared using different proportions of biodiesel (99.5%, 98.5% & 97.5%) and 2-ethylhexyl nitrate (EHN) (0.5%, 1.5% & 2.5%) on the performance and emission characteristics of diesel engine were investigated at different loads (2000, 2500 & 3000 W). load, % blends of EHN and % blends of biodiesel with three levels of each were taken as control parameters. Optimum result was biodiesel ratio of 99.2%, EHN ratio of 1.3%, and the load of 2300 W were the optimum results for the best performance and emission values.

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III. CONCLUSION

I. Due to the increasing awareness of the depletion of fossil fuel resources and environmental issues, biodiesel became more attractive in the recent years. Biodiesel production is a promising and important field of research because the relevance it gains from the rising petroleum price and its environmental advantages. In present situation, there is much possibility of multifold increase in the research in biodiesel, vegetable oils like soybean oil, rapeseeds oil, sunflower oil, methanol, ethanol and other alternate fuels.

II. Considering alternate fuels as a substitute of diesel, Researchers are continuously finding best alternative solution, which gives the best performance and fuel characteristics. In such multivariate problem, use of nonlinear techniques like Design of Experiments (DoE), fuzzy logic and neural network are suitable to explore the combined effects of input parameters.

III. The optimum operating parameters for a given system can be determined by using experimental techniques but it will be time consuming and expensive when the number of parameters are in the order of 20, 30 etc., like in the case of IC engines. In such situations mathematical modeling will be a very useful tool for optimizing the parameters. Such a mathematical tool is Design of Experiment.

IV. The objective of the study is not only to describe relevant work, but also to provide an understanding of the methods by which we can improve the different characteristics of IC engines by using best possible biodiesel blend.

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