Mitigation of Exhaust Emission from CRDI Diesel Engine through Post Fuel Injection Strategy with the use of Central Composite Design

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Abstract

In this work, post fuel injection strategy was introduce to mitigate the emission from a common-rail diesel engine with mahua biofuel blend (B25) have been discussed. Post fuel injection strategy has been achieved by common rail direct injection (CRDI) system fitted with conventional single cylinder Kirloskar made TV-I diesel engine. The central composite face cantered (CCFC) design with two factors was utilized in this work to analyse and optimize on post injection process variables in CRDI diesel engine. The consequence of post injection process variables such as post injection quantity (5-30%) and post injection fuel dwell time (5-30° crank angle after uncontrolled combustion phase) is studied. The uncontrolled combustion phase ended at 12.21° of crank angle after top dead centre (ATDC).

The outcome of post fuel strategy on emissions of a CRDI diesel engine is examined. By retarding the timing and varying the quantity of post fuel injection decreases the engine emissions. Post fuel injection at retarded injection angles provides to decrease the HC, CO and NOx while suppressing the fuel consumption. These results caused by the less quantity of adhering fuel to the engine cylinder wall during combustion.

Keywords: CRDI diesel engine, Post injection, Performance, Emission, Central composite design.

Introduction

The prime element to influence the world economy and international politics is the sustainability of petro-fuel reserves, which is a major supply of international energy source[1]. The energy demand is ever-increasing more rapidly as a result of excessively used of fuels[2]. The increase of demand forecast forces the researchers to develop the new technology in the field of automobile industry[3].

Diesel engines have high fuel economy, maximum thermal efficiency, high resilience and reliability which have consequences in them becoming the preferred in all heavy duty and several light duty vehicles[4]. The higher thermal efficiency of the diesel engines results attained through the maximum power output with minimum fuel consumption because of a high compression ratio[5]. However, diesel engines emit lower levels of emissions such as CO and HC when compared with gasoline engines[6]. The most challenging task in diesel emissions controls is the combination of smoke and NO_x emissions[7].

Much research has been done on biodiesel as an alternative renewable fuel since both fuels have similar characteristics to diesel fuel. Biodiesel has special advantages in terms of higher cetane number, lower sulphur and lower aromatic hydrocarbons[8]. The biofuel is simple to coalesce with conventional diesel and it can be employed in existing diesel engines without requiring any major modification.

The enhancement of diesel engines for passenger cars to meet the terms with the rigid emission norms is very much association to the sustained improvement of the fuel injection system[9]. The developing tendency in the diesel engine industry is in the direction of extensive use of an electronic assisted injection system which injects the fuel by several points in the cycle[10]. The most important difference among CRDI system and a conventional fuel injection system is the open selection of the fuel injection pressure and fuel injection timings[11].

Besides, CRDI injection systems are proficient of high injection pressure and multiple choices of injections. CRDI is a smart approach of controlling diesel engine emissions with the use of contemporary computer systems. CRDI helps to get enhanced performance and decrease harmful emissions from conventional diesel engines. Conventional diesel engines are poor in performance and noisy compared to a CRDI diesel engine. CRDI system is also referred to by alike or dissimilar names. A post injection schedule where some quantity of fuel injected is split into many portions after the main injection[12]. The split injections are frequently illustrated by the quantity of the total fuel that each fuel injection contains[13]. Many studies explore the consequences of split fuel injections through constraint sweep ups with the share of fuel transferred between the injections, for instance from 05% in the primary injection and 95% in the main injection (pilot fuel injection), to 95% in the first and 05% in the second injection (post fuel injection). Thus, split fuel injection is a big kind of multiple fuel injections, by which post fuel injections are a division.

Previous studies have proved that because of the post fuel timing, the injected fuel burns and the enhanced temperature in after burning phase through the further heat release can improve the soot particles oxidation and reduce the unburned hydrocarbon rate from the main fuel injection, thus reducing engine emissions[14]. In this work, the part amount of fuel (5 to 20%) is injected at different dwell timings after the after uncontrolled combustion phase and the outcomes of post fuel injection on CRDI engine exhaust emissions like CO, HC, NOx and smoke was analysed.

Experimental Design with Central Composite Design: The central composite method is an investigational design employed to attain more number of data from a least number of try-outs about a system. In this study, face centred central composite tentative design was utilized to determine the optimal conditions also analyse consequence of two different variables (post fuel injection quantity (5-20%) and post fuel injection dwell time (5-30° after uncontrolled combustion phase) on five responses like fuel consumption, NOx, HC, CO and smoke emissions of CRDI diesel engine.

Since the initial investigational outcomes, process variables with their ranges were determined. Subsequent to range of independent variables and their assortments, testing was conducted based on a central composite face cantered design and every self-governing variable were coded between the levels of -1, 0 and +1. During this experiment, 13 experiments were conducted to facilitate the assessment of neat error was conducted and the number tests were determined from the following derivation [04]:

$$N = 2^n + 2n + n_c$$

where N denotes the number of trials be necessitated; c denotes the number of centre points and n denotes the number of factors used in experiments. The experiments were randomized with the intent of curtail the consequences of unpredicted inconsistency in the responses by reason of inappropriate factors. The second-order polynomial formula was employed with the intent of extend an investigational model which correlated the retorts to independent variables used. The common structure of second order polynomial equation is:

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \sum_{t} \sum_{<j}^{k} \beta_{ij} X_i X_j$$

whereas letter “Y” denotes the response; β_0 is the model capture coefficient; βj, βjj and βij are interface coefficients of linear, second order polynomial and the quadratic terms; Xi and Xj are the variables, respectively whereas k denotes the number of independent constraints.

Impact of Post Injection on Process Variables: During this work, two factors at face cantered (FC) design was employed to analyze the effect of process variables for instance post fuel injection dwell time and post injection fuel quantity during combustion. Response surfaces of 3D were made from the created models. The plots of response surfaces are depictions of deterioration derivations which show most important outcomes of self-determining variables. These plots are simple for recognize the interfaces among duos of sovereign variables on three dimensional responses and as well become familiar with in the direction of establish their finest intensities. Figures 1 to 4 shows the residual contrives of CO, HC, NOx and smoke respectively.

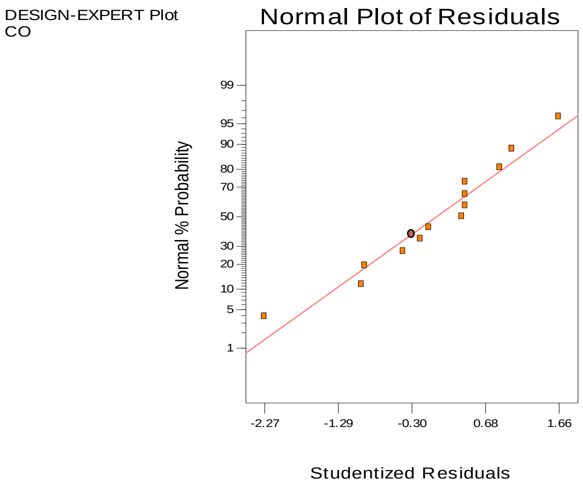

Figure 1: Contrive of residuals for CO

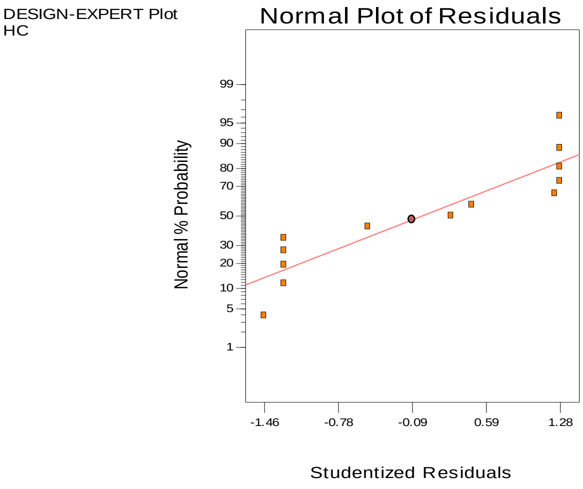

Figure 2: Contrive of residuals for HC

Figure 3: Contrive of residuals for NOx

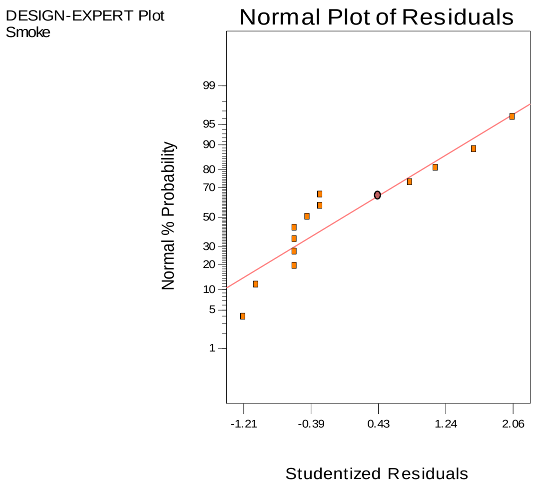

Figure 4: Contrive of residuals for smoke

CRDI Diesel Engine Setup: Experiments were performed on Kirloskar TV1 assisted by common rail direct injection fuel system, single cylinder and water cooled diesel engine. The engine was 3.7 kW rated power and driven at an invariable speed of 1600 rpm. The line diagram of the CRDI diesel engine setup is depicted in Figure 5. The illustration of ECM software with post fuel injection is depicted in Figure 6. The accumulator present in the common rail system is bestowed that four fuel injector ports by means of highest pressure capable of 120 MPa with volume of 18 cm^3.

The pressure interpretations from the sensor are transfer to engine ECM for closed-loop to control the fuel injection pressure. Pressure deviation and combustion constraints, for instance the direct heat release rate and the angles of 5, 25, 50 and 95 % fraction of fuel mass burned were obtained as of the pressure outlines via the Legion brothers made Engine test express 2014” software. The smoke meter employed in this work was AVL 415 erratic sampling smoke meter. An AVL made Di-gas analyser used for these investigations to analyse the engine exhaust gases. The measurement system has accuracy of 2 % over a maximum of 6 hours and linearity of the signals of +/-1 %.

Experimental Results and Discussions: The function of the CRDI diesel engine was establish to be exceptionally smooth during the maximum load condition, exclusive of at all functioning troubles for the post fuel injection strategy. A small quantity of biofuel blend from the main injection was injected after the after uncontrolled combustion phase and the consequence of post fuel injection on engine exhaust emissions were discussed. The three dimensional response surface for carbon monoxide emission regarding biofuel quantity of post injection with the fuel dwell timing with central composite design was depicted in figure 7.

From the figure, it is found that post fuel injection after uncontrolled combustion phase effectively reduce the CO emission. It may be due to post fuel injection can oxidize and burn the unburned hydrocarbon after diffusion combustion phase. The outcome of the post fuel injection turn into more effective in the reduction of CO emission when 12.5-17.5 (fuel quantity-dwell timing) case.

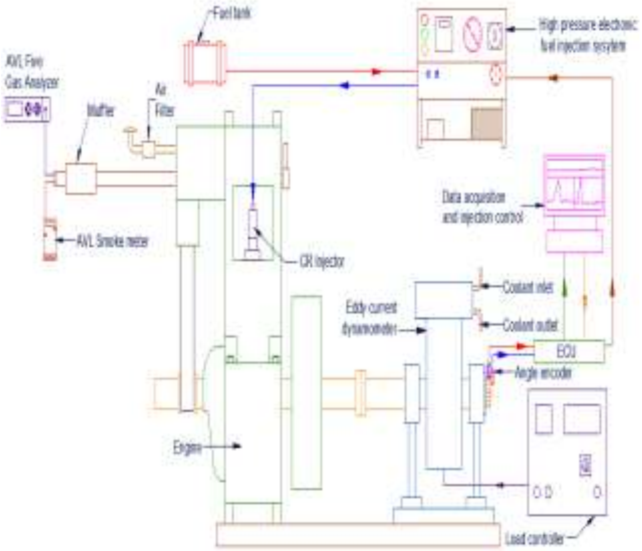

Figure 5: Schematic diagram of the CRDI diesel engine setup

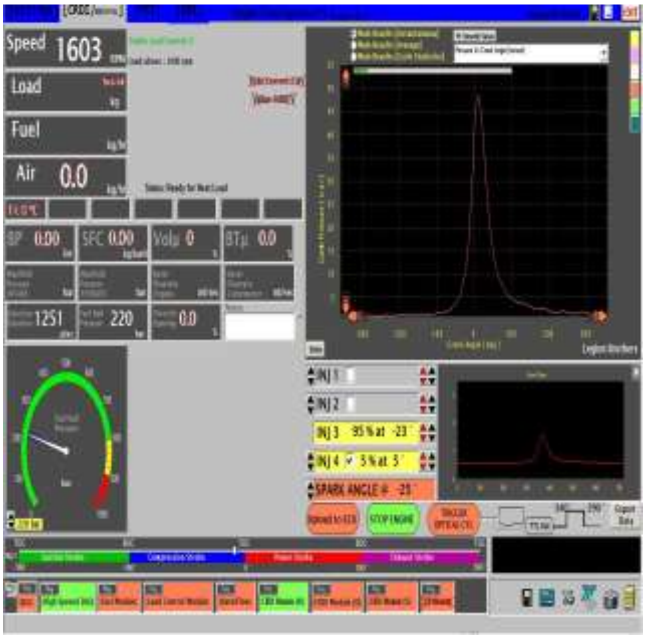

Figure 6: Image of CRDI engine management system with post fuel injection

The three dimensional response surface for HC emission as regards of post fuel injection quantity along with biofuel dwell timing with CCD was depicted in Figure 8. From the results obtained through post injection of biofuel blend, the HC emissions were decreased when post fuel dwell timing is move ahead of after uncontrolled combustion phase. Especially, the HC emissions were decreasing when the post fuel injection dwell timing is move ahead from 5° to 20° of after uncontrolled combustion phase. This is due to sufficient combustion is made by reason of overcome the wall wetting of the biofuel spray in the combustion chamber wall by injection of small amount of post fuel in after uncontrolled combustion phase beyond the injection timing of 5°. From the results it is scrutinized that biofuel quantity takes part in an imperative responsibility in reduction of emissions during post fuel injection. Fuel quantity was increased from 5% to 20% in this evaluation. The optimum fuel quantity found as 12.5% with the dwell time of 17.5° after uncontrolled combustion phase.

The three dimensional response surfaces for NOx emission as regards of post biofuel injection amount and biofuel dwell timing was depicted in figure 9. Prologue of post biofuel injection, it has been found that the peak flame temperature when the diffusion combustion phase of mahua methyl ester biofuel decreased. As a result of low peak flame temperature, the NOx emission was found reduced. Consequence of the post biofuel injection turn into new considerable in decline of NOx emission whilst 12.5-17.5 (fuel quantity-dwell timing) case. It reduces the peak heat release during the diffusion combustion period of MME20 fuel blend moreover mitigates the NOx configuration rate drastically proportionate to single fuel injection. Compared the 12.5 fuel quantity with delayed injection dwell time of 17.5 degrees was better to single biofuel injection.

Figure 10 shows the three dimensional response surfaces for smoke emission concerning post biofuel injection quantity along with dwell timing. It is studied from the figure, which smoke emission marginally reduces with introduction of post fuel injection after uncontrolled combustion phase. Decreased smoke is studied during the case of 12.5-17.5 (fuel quantity-dwell timing). Decreased smoke could be happened because of enhanced combustion features of post injected biodiesel blended diesel fuel after the diffusion combustion and reduce the both soot and smoke emissions. The smoke opacity decreased whilst the post biofuel blend quantity rose from 5 to 12.5%. Beyond 12.5%, the smoke was found slightly increased. The post injection dwell timings also played a vital role in reduction of smoke emission. The dwell timing up to 17.5° after diffusion combustion phase is effectively reduce the smoke emission.

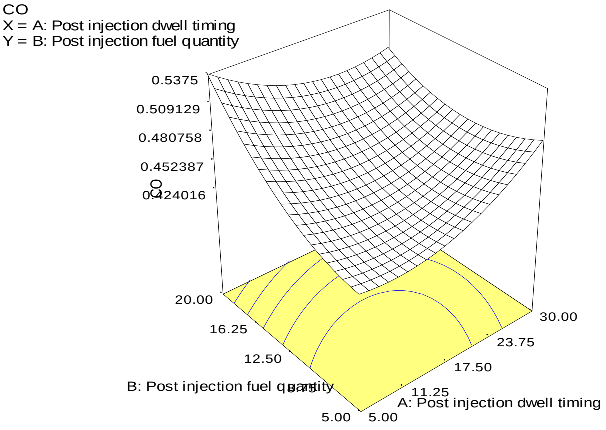

Figure 7: Three dimensional response surface for CO emission

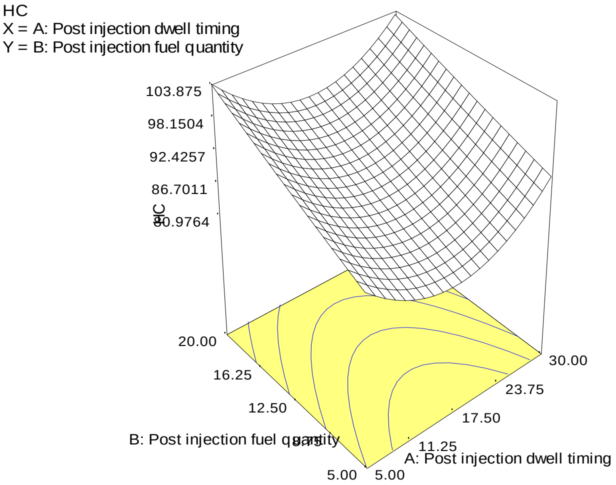

Figure 8: Three dimensional response surface for HC emission

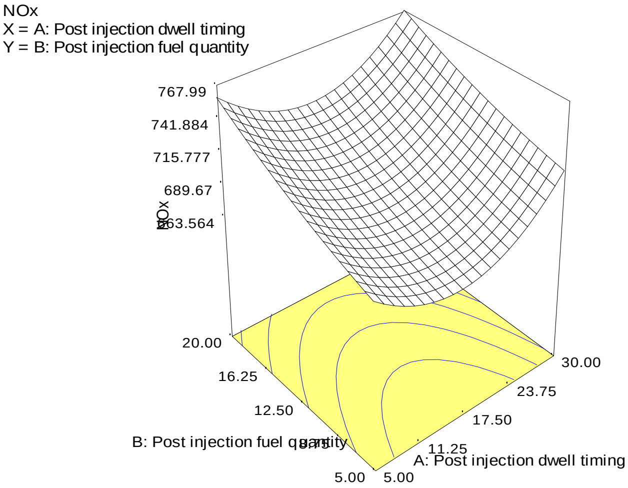

Figure 9: Three dimensional response surface for NOx emission

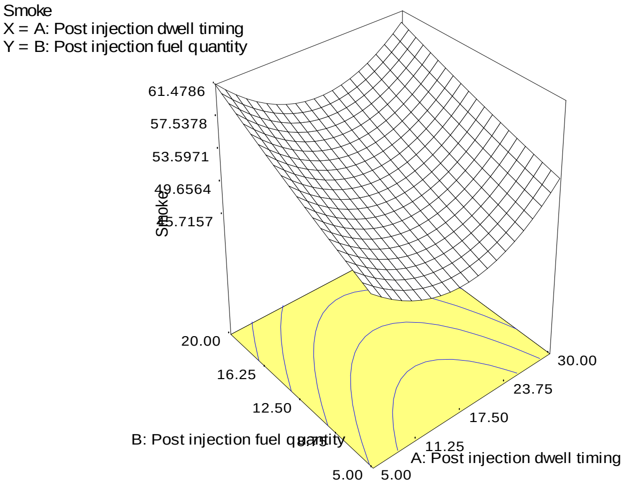

Figure 10: Three dimensional response surface for smoke emission

Conclusion

In this investigation, high pressure common rail diesel engine emission characteristics studied by using post fuel injection strategy. The quantity of post injection of mahua biofuel blend is differed from 5 to 20% and the dwell timing is varied from 5 to 30° after the uncontrolled combustion phase. The following consequences can be bring to a closed from the above experimental study

- The decline in CO emission found by post fuel injection in CRDI diesel engine with mahua biofuel blend. 12.5-17.5 (fuel quantity-dwell timing) post fuel injection case showing a 21.87% reduction in CO compared with single injection.
- The post fuel injection strategy was efficient in declining HC emissions from the CRDI test diesel engine. HC emissions with 12.5-17.5 (fuel quantity-dwell timing) and 20-30 (fuel quantity-dwell timing) post fuel injection cases are declined by 21.23% and by 29.20%, respectively
- NOx emission noticeably decreases by introducing post fuel injection compared to single injection.
- The smoke emission in the case of post fuel injection is mainly depending on the fuel quantity. The amount of post injection fuel increased from 5 to 12.5 with the dwell period of 10-15° after the uncontrolled combustion phase the smoke emission was found reduced.

Hence, post fuel injection strategy is efficient in reducing the diesel engine exhaust harmful emissions.

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