# Modeling and Grey Relational Multi-response Optimization Performance Efficiency of Diesel Engine

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**Abstract -** *In conclusion the optimal settings of those factors for better performance of the tested engine which are 25% engine load 20% hydrogen 50 ppm mwcnt 220 bar ignition pressure and 21 obTDC ignition timing*

*In conclusion the figure shows the optimal settings of those factors for better performance of the tested engine which are 25% engine load 20% hydrogen 50 ppm mwcnt 220 bar ignition pressure and 21 obTDC ignition timing. Table 6 displays the variance analysis (ANOVA) of the engine performance. It shows the influence and importance of each component on the performance as a whole. Engine load is discovered to be the most important factor, contributing 71.47% to the total, followed by hydrogen (15.36%) and MWCNTs (8.66%). Ignition pressure and timing made a very small contribution to the other two elements. To increase engine performance efficiency, substantial focus should be given to the aspects that have a significant impact.*

***Key Words***: Diesel engine, grey relationship optimisation, thermal efficiency of the brakes, fuel use, and emissions

## 1. INTRODUCTION

Both human health and the ecosystem are negatively impacted by this phenomenon (Lin et al., 2011; Arbab et al., 2013). Numerous studies have demonstrated that fossil fuels have a considerable impact on the thinning of the ozone layer (Oparanti et al., 2022). According to the International Energy Agency (IEA), the rate of energy consumption would be approximately 53% by 2030 (Taufiqurrahmi & Bhatia, 2011). Meaning that the negative impact of using fossil fuels on the ozone layer's deterioration by 2030 is likely to be intolerable. Numerous studies have been done on the various approaches to overcome these difficulties. A single-cylinder, direct-injection diesel engine's potential for increased performance efficiency and decreased combustion emissions was investigated by Abu-Jrai et al. in 2009. In their research, they introduced simulated reformer product gas to to compare engine performance, combustion, and emissions under various operating situations to a normal ultra-low Sulphur diesel (ULSD) and a substitute ultra-clean synthetic GTL (gas-to-liquid) fuel. They came to the conclusion that a perfect mixture of GTL and simulated reformer product gas greatly reduced NOx and smoke emissions. An investigation on the combustion and emissions of a diesel direct engine injection (DI) running on diesel-oxygenate mixes was conducted by Ren et al. in 2008. They found that regardless of the types of oxygenating additions, there was a reduction in smoke concentration; however, the smoke decreased when the oxygen mass fraction within the blends was increased without raising the NOx and engine thermal efficiency. On the other hand, it had been shown that when the oxygen mass fraction increased in the blends, the amounts of CO and HC decreased. To study the combustion and emissions of the compression ignition of the engine, Li et al. (2015) fueled an instant injection diesel with pentanol. Additionally, there are numerous studies on the optimisation of input variables for diesel engine emissions and performance efficiency. The performance and emissions of a diesel engine running on biodiesel were optimised by Sivaramakrishnan and Ravikumar in 2014. It had been discovered that the test engine performed best at a compression ratio of 17.9, a fuel blend of 10, and a power output of 3.81 kW. Leung and colleagues (2006) optimised the injection pressure, timing, and plunger diameter of the fuel pump.

## 2 Methodologies:

The study by Manigandan et al. (2020) was followed by this one. Their effort provided the experimental data that was needed for analysis. The experimental factors, experimental runs, and corresponding data for the analysis in this work are displayed in Numbers 1, 2, and 3, respectively. Software called Minitab 16 was used for the Taguchi design and modelling, and Origin 19 was used for interaction plots and other types of plots. The experimental data shown in Table 3 underwent a grey relational analysis. With the use of grey relational generation, the data was first normalized. According to Equation 1, the higher-the-better normalization condition was used to normalize the break thermal efficiency (BTE).

So Taguchi DoE has been used to identify the correct combination of selected design factor and their levels in present study. For the present study, factors and levels were selected based on literature review are mentioned in Table 2

Table 2.Factors and their levels

| Factors and their levels. | | | | | |
|---|---|---|---|---|---|
| Symbol | Factors | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
| A | Engine load (%) | 25 | 50 | 75 | 100 |
| B | Hydrogen (%) | 0 | 10 | 20 | 30 |
| C | Nanoparticles (ppm) | 0 | 30 | 50 | 80 |
| D | Ignition pressure (bar) | 180 | 200 | 220 | 240 |
| E | Ignition timing (0bTDC) | 21 | 23 | 27 | 31 |

Table 2.1 Specification of the test engine

Parameters Specifications

General details Single cylinder, 4 S, constant speed compression ignition

Engine, Dual combustion

Cool Air cooled

Bore 86 mm

Stroke 106 mm

Swept volume 616.56 cc

Compression ratio 16.5:1

Injection Pressure 240 bar

Fuel injection Piston pump

Injector Solenoid controlled

Rated speed 1800 rpm

Table 2.2Properties of fuel

| Specification | Diesel | Hydrogen |
|---|---|---|
| Density at ambient (kg/m3) | 824 | 0.081 |
| Lower heat value (MJ/kg) | 42.5 | 120 |
| Higher heat value (MJ/kg) | 44.8 | 141.9 |
| Specific gravity | 0.83 0 | .091 |
| Cetane number | 44–55 | 0 |
| Carbon content | (wt%) 86 | 0 |
| Hydrogen content | (wt%) 13 | 100 |
| Mole weight (g) | 148.3 | 1.92 |
| Auto-ignition (K) | 524 | 854 |
| Octane number | 30 | 130 |

| Exp. runs | Engine load (%) | Hydrogen (%) | MWCNTs (ppm) | Ignition pressure (bar) | Ignition timing (°bTDC) |
|---|---|---|---|---|---|
| 1 | 25 | 0 | 0 | 180 | 21 |
| 2 | 25 | 10 | 30 | 200 | 23 |
| 3 | 25 | 20 | 50 | 220 | 27 |
| 4 | 25 | 30 | 80 | 240 | 31 |
| 5 | 50 | 0 | 30 | 220 | 31 |
| 6 | 50 | 10 | 0 | 240 | 27 |
| 7 | 50 | 20 | 80 | 180 | 23 |
| 8 | 50 | 30 | 50 | 200 | 21 |
| 9 | 75 | 0 | 50 | 240 | 23 |
| 10 | 75 | 10 | 80 | 220 | 21 |
| 11 | 75 | 20 | 0 | 200 | 31 |
| 12 | 75 | 30 | 30 | 180 | 27 |
| 13 | 100 | 0 | 80 | 200 | 27 |
| 14 | 100 | 10 | 50 | 180 | 31 |
| 15 | 100 | 20 | 30 | 240 | 21 |
| 16 | 100 | 30 | 0 | 220 | 23 |

Table 2.3 L16 Orthogonal array outcome [13]

| Exp. runs | BTE | BSFC | HC | NOx | CO | $CO_2$ |
|---|---|---|---|---|---|---|
| 1 | 32.65 | 755 | 8.65 | 120 | 0.09 | 2.61 |
| 2 | 33.88 | 735 | 8.5 | 112 | 0.08 | 2.55 |
| 3 | 37.3 | 708 | 8 | 108 | 0.05 | 2.1 |
| 4 | 35.25 | 715 | 8.25 | 105 | 0.06 | 2.32 |
| 5 | 33.95 | 662 | 10.8 | 210 | 0.128 | 4.05 |
| 6 | 32.15 | 625 | 10.2 | 235 | 0.125 | 3.95 |
| 7 | 34.35 | 539 | 9.4 | 210 | 0.12 | 3.8 |
| 8 | 36.98 | 468 | 9.2 | 198 | 0.1 | 3.52 |
| 9 | 33.55 | 490 | 13.05 | 265 | 0.135 | 5.52 |
| 10 | 35.12 | 452 | 12.19 | 265 | 0.149 | 4.32 |
| 11 | 33.84 | 485 | 11.95 | 280 | 0.14 | 4.25 |
| 12 | 34.5 | 435 | 11.25 | 242 | 0.132 | 4.15 |
| 13 | 33.56 | 375 | 14.68 | 365 | 0.158 | 7.25 |
| 14 | 34.1 | 355 | 13.72 | 315 | 0.155 | 6.75 |
| 15 | 35.95 | 348 | 12.68 | 298 | 0.145 | 4.45 |
| 16 | 35.05 | 368 | 15.66 | 338 | 0.151 | 6.2 |

The requirement for the highest possible break thermal efficiency is the basis for the higher-is-better normalization. After that, Equation 2's smaller-is-better normalization condition was used to normalize the remaining data, which included break specific fuel consumption (BSFC), hydrocarbons (HC), nitrogen oxide (NOx), carbon monoxide (CO), and carbon dioxide (CO2). We needed those qualities to be as low as feasible, thus we chose the smaller-the-better normalization condition. The six performance traits were compared to an ideal sequence, xo(k) (k = 1, 2,..., 16).

## 3 RESULTS AND DISCUSSIONS:

The second normalized formula, type factor, is acceptable for defects.

$$x_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \qquad (1)$$

The first normalized formula is suitable for the benefit – type factor.

$$x_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \tag{2}$$

The second normalized formula is suitable for defect – type factor.

$$x_i(k) = \frac{|x_i(k) - x_0(k)|}{\max x_i(k) - x_0(k)} \tag{3}$$

The $xi\ (k)$ is the data being pre-processed for the ith experiment, and $yi\ (k)$ is the initial sequence of the mean of the responses. The deviation sequence (Equation 3) was subsequently calculated to enable the determination of grey relational coefficient (GRC). The grey relational generation and the deviation sequence of the six experimental data are shown in Table 4.

$$\Delta x_i(k) = |x_0(k) - x_i(k)| \tag{4}$$

And the maximum and the minimum difference should be found.

a) b) The p distinguishing the coefficient is a number that varies from 0 to 1.. The distinguishing coefficient p is usually set to 0.5.

In analysis, Grey relational coefficient $\xi$ can be expressed as follows [15]:

$$\xi_i(k) = \frac{\Delta \min + p\Delta \max}{\Delta x_i(k) + p\Delta \max} \tag{5}$$

And then the relational degree follows as:

$$r_i = \sum [w(k)\xi(k)] \tag{6}$$

Where I (k) is the GRC value of the particular experimental data determined as a function of min and max, the experimental data's minimal and maximum deviations.is the distinguishing coefficient, with a widely accepted value of 0.5 (Mahmoudi et al., 2020; Abifarin et al., 2021a).

| Deviatin sequence | | | | | |
|---|---|---|---|---|---|
| BTE | BSFC | HC | NOx | CO | CO2 |
| 0.903 | 1.000 | 0.085 | 0.058 | 0.507 | 0.099 |
| 0.664 | 0.951 | 0.065 | 0.027 | 0.435 | 0.087 |
| 0.000 | 0.885 | 0.000 | 0.012 | 0.217 | 0.000 |
| 0.398 | 0.902 | 0.033 | 0.000 | 0.290 | 0.043 |
| 0.650 | 0.771 | 0.366 | 0.404 | 0.783 | 0.379 |
| 1.000 | 0.681 | 0.287 | 0.500 | 0.761 | 0.359 |
| 0.573 | 0.469 | 0.183 | 0.404 | 0.000 | 0.330 |
| 0.062 | 0.295 | 0.157 | 0.358 | 0.580 | 0.276 |
| 0.728 | 0.349 | 0.659 | 0.615 | 0.833 | 0.664 |
| 0.423 | 0.256 | 0.547 | 0.615 | 0.935 | 0.431 |
| 0.672 | 0.337 | 0.516 | 0.673 | 0.870 | 0.417 |
| 0.544 | 0.214 | 0.424 | 0.527 | 0.812 | 0.398 |
| 0.726 | 0.066 | 0.872 | 1.000 | 1.000 | 1.000 |
| 0.621 | 0.017 | 0.747 | 0.808 | 0.978 | 0.903 |
| 0.262 | 0.000 | 0.611 | 0.742 | 0.906 | 0.462 |
| 0.437 | 0.049 | 1.000 | 0.896 | 0.949 | 0.796 |
| | | | | | |
| Delta Min | 0.000 | | | | |
| Delta Max | 1 | | | | |

| Grey Relation Coefficient | | | | | |
|---|---|---|---|---|---|
| BTE | BSFC | HC | NOx | CO | CO2 |
| 0.356 | 0.333 | 0.855 | 0.897 | 0.496 | 0.835 |
| 0.430 | 0.345 | 0.885 | 0.949 | 0.535 | 0.851 |
| 1.000 | 0.361 | 1.000 | 0.977 | 0.697 | 1.000 |
| 0.557 | 0.357 | 0.939 | 1.000 | 0.633 | 0.921 |
| 0.435 | 0.393 | 0.578 | 0.553 | 0.390 | 0.569 |
| 0.333 | 0.424 | 0.635 | 0.500 | 0.397 | 0.582 |
| 0.466 | 0.516 | 0.732 | 0.553 | 1.000 | 0.602 |
| 0.889 | 0.629 | 0.761 | 0.583 | 0.463 | 0.645 |
| 0.407 | 0.589 | 0.431 | 0.448 | 0.375 | 0.430 |
| 0.542 | 0.662 | 0.478 | 0.448 | 0.348 | 0.537 |
| 0.427 | 0.598 | 0.492 | 0.426 | 0.365 | 0.545 |
| 0.479 | 0.701 | 0.541 | 0.487 | 0.381 | 0.557 |
| 0.408 | 0.883 | 0.364 | 0.333 | 0.333 | 0.333 |
| 0.446 | 0.967 | 0.401 | 0.382 | 0.338 | 0.356 |
| 0.656 | 1.000 | 0.450 | 0.402 | 0.356 | 0.520 |
| 0.534 | 0.911 | 0.333 | 0.358 | 0.345 | 0.386 |

| Grey Relation Grade | |
|---|---|
| GRG | RANK |
| 0.629 | 6.000 |
| 0.666 | 3.000 |
| 0.839 | 1.000 |
| 0.734 | 2.000 |
| 0.486 | 10.000 |
| 0.478 | 12.000 |
| 0.645 | 5.000 |
| 0.662 | 4.000 |
| 0.447 | 15.000 |
| 0.502 | 9.000 |
| 0.475 | 14.000 |
| 0.524 | 8.000 |
| 0.443 | 16.000 |
| 0.482 | 11.000 |
| 0.564 | 7.000 |
| 0.478 | 13.000 |

| Factors | Degree of Freedom (DF) | Adj SS | Adj MS | Contribution (%) | Remark |
|---|---|---|---|---|---|
| Engine load (%) | 3 | 0.17646 | 0.05882 | 71.47 | Most significant |
| Hydrogen (%) | 3 | 0.03792 | 0.01264 | 15.36 | Significant |
| MWCNTs (ppm) | 3 | 0.02138 | 0.00713 | 8.66 | Significant |
| Ignition pressure (bar) | 3 | 0.00321 | 0.00107 | 1.30 | Insignificant |
| Ignition timing (°bTDC) | 3 | 0.00796 | 0.00265 | 3.22 | Insignificant |
| Residual error | 0 | | | | - |
| Total | 15 | 0.24693 | 0.08231 | | |

## 4. Conclusion

Except for ignition timing, the results demonstrated a consistent behavioral pattern caused by engine conditions. The optimum values for Engine load (%), hydrogen, multi-walled carbon nanotubes (MWCNTs), ignition pressure, and timingas 25%Engine load (%), 20%hydrogen, Nanoparticles 50 (ppm).220(bar)ignition pressureand 31Ignition timing (0bTDC), respectively. The optimum values for BTE, BSFC, hydrocarbons (HC), nitrogen oxide (NOx), carbon monoxide (CO), and carbon dioxide (CO2) are 36.0842,714.4110,8.09,113.16,0.0583 and 2.3414 respectively. The trial runs taken into account in the analysis did not include the discovered optimal settings for greater engine performance. Although confirmation analysis indicated that there was a chance that the predicted ideal engine performance was within the confidence bound, experimental work based on the obtained optimal settings is still required effectiveness of the confirmation analysis. Engine load was the most significant component, according to the analysis of variance (ANOVA), contributing to Engine load is discovered to be the most important factor, contributing 71.47% to the total, followed by hydrogen (15.36%) and MWCNTs (8.66%). Ignition pressure and timing made a very small contribution to the other two elements. To increase engine performance efficiency, substantial focus should be given to the aspects that significantly affect.

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