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# EXPERIMENTAL AND MATHEMATICAL INVESTIGATION ON PERFORMANCE AND EMISSION CHARACTERISTICS OF OXYGEN ENRICHED AIR IN INTAKE OF A SINGLE CYLINDER DIESEL ENGINE

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## ABSTRACT:

This research revealed that the single cylinder diesel engine performance and emission characteristics are improved by the oxygen content enriched intake air and was varied between 21% to 27 % (ie., 21,23,25,27% by the volume). The effects of enriched oxygen with different loads are analyzed in terms of brake thermal efficiency, specific fuel consumption, and also the environmental pollutant like NOx, CO, HC and Smoke. The mathematical experiment were designed using a statistical tool know as design expert based on response surface modeling. Using RSM to predict the response parameter like brake thermal efficiency, brake specific fuel consumption, carbon monoxide, hydrocarbon, nitrogen oxides and smoke. Optimization of the input and response parameters is also done using desirability approach. Finally a software tool is developed using LabVIEW software for predicting engine parameters when the engine input parameters are given.

**Indexing terms/Keywords:** oxygen enrichment, diesel engine performance, environmental engine pollutant, Response surface methodology, Design of Experiments, flow control valve, LabVIEW.

## Academic Discipline and Sub-Disciplines

Mechanical Engineering, Thermal Engineering,

## SUBJECT CLASSIFICATION

Engine Performance and Emission

## TYPE (METHOD/APPROACH)

Experimental and Mathematical Analysis

## 1. INTRODUCTION

Diesel engine is increasing in reputation due to its higher thermal efficiency because of higher compression ratio; un-throttled operation, and lean combustion operation. The approximate composition of diesel exhaust gas is 67% N2, 12% CO2, 11% H2O and 9% O2 [1]. The four main environmental pollutants of diesel engine are CO, HC, PM and NOx. The troubles of carbon monoxide (CO) include, it binds to hemoglobin and inhibits its capacity to transfer oxygen, leading to asphyxiation, and this can affect the function of different organs, resulting in impaired concentration, slow reflexes, and confusion [2-5]. The problems of hydrocarbon (HC) include respiratory tract irritation and cause cancer [6-7]. The use of oxygen enrichment in diesel engine shows a considerable decrease in unburned hydrocarbon, carbon monoxide emissions and smoke while an oxides of nitrogen emissions increases. The after treatment technology require additional pressure, components and cost. The use of after treatment technology and alternate fuels reduce diesel exhaust emissions. The after treatment technology require additional pressure, components and cost. Out of the available alternate fuels such as bio fuels, alcohols, biogas, and biodiesel, alcohol is very much prominent and talented alternative fuel due to its storage facility and handling. The alcohols are oxygenated fuels, has one or more oxygen, which contributes to the combustion. The advantages of alcohols are made out of organic material, produces higher combustion pressures, have better combustion characteristics, higher performance due to increased volumetric efficiency, safety for fire, leakage and spillages, lower evaporative emissions, very small carbon content, and do not need any special transportation. One of the alcohols which is technically and economically suitable as fuel for internal combustion engines and have simplest molecular structure is ethanol. Ethanol is produced from biomass transformation.Cole et al [8] examined the technical and economic feasibility of diesel engines for stationary cogeneration applications using oxygen-enriched combustion air, water injection, and low-grade fuels. The effects of these modifications on the diesel engine were studied with a computer simulation: results are presented in a companion paper. Four methods of oxygen enrichment, purchases LOX, cryogenic separation, pressure-swing adsorption (PSA), and membrane enrichment (ME) were investigated. Two of these methods, PSA and ME, are particularly amenable to integration with a stationary engine. After the technical evaluation was completed, the economic performance of the options was analyzed. Results show that the economic viability of the system depends primarily on switching to a cheaper, low-grade fuel; the optimum oxygen enrichment is the minimum that will enable the engine to burn the low-grade fuel. Donahue and Foster [9] found that the promising advantages of using oxygen enhanced combustion is that inferior quality fuels can be used in the engines without affecting overall performance of the engines. Marr et al [10] conducted on a six-cylinder diesel engine to study the impacts of controlled factors (i.e., oxygen content of the combustion air, water content of the fuel, fuel-flow rate, and fuel-injection timing) on engine performance and emissions using Taguchi techniques. Separate experiments were conducted using a commercial-grade No. 2-diesel and a lower-grade No. 6-diesel fuel. This paper reports the test results for No. 6 fuel. Oxygen enrichment improved the combustion process with the lower-grade fuel. There was no observable change in turbocharger performance due to oxygen enrichment. The results showed significant reductions in smoke and particulate emissions, a small increase in thermal efficiency and a large increase in NOx emissions when oxygen-enriched air was used. The effect of water-emulsified fuel on NOx emissions was negligible. When the engine was operated with No. 6 fuel and normal air, the thermal efficiency was lower and the exhaust emissions in general were higher than with No. 2 fuel. Juhun Song et al [11] accomplished oxygen enrichment by connecting an oxygen generator to the intake air surge tank, while fuel oxygenation was accomplished using two compounds with different cetane number and molecular structure. The key observations are that both intake oxygen enrichment and fuel oxygenation via linear structure oxygenated molecules are effective for reduction of diesel particulate matter, yielding even greater reductions in PM emissions than for fuel oxygenation via ring-structured oxygenated molecules. However, NOx emissions are greatly increased with intake oxygen enrichment, owing to either increased availability of atomic oxygen or attainment of a higher temperature during leaner combustion. Liang et al [12] varied Oxygen concentration of intake air varied from 21% to 24% by volume. Water content in tested fuels was 0%, 10%, 20%, and 30% by volume respectively. The result indicated that lower BSFC, higher cylinder pressure and shorter ignition delay were observed when OEC was applied, while opposite trends were found when using WDE. Reduction of PM and NOx can be realized simultaneously by applying OE combined with WDE. Particle number concentration of nucleation mode increases with increasing oxygen concentration, while that of accumulation mode decreases. Optimal operating condition was realized when water content in emulsion was below 20% along with low oxygen enrichment. Wei Zhang et al [13] conducted on a turbocharged direct injection diesel engine, and oxygen-enriched and EGR techniques were used to produce lower NO–Smoke emission than the unmodified engine under the same fuel supply rate curve and fuel supply quantity. Jibanananda Jena and Rahul Dev Misra [14] analyzed along with heat release analysis are conducted on a natural aspirated diesel engine fuelled separately with palm biodiesel (PB), karanja biodiesel (KB), and petrodiesel (PD) using the experimental data. Since the engine performs best at about 85% loading condition, the energetic and exergetic performance parameters of the engine are evaluated at 85% loading condition for each type of fuel. The aim of the study is to determine the effect of fuel oxygen on energy and exergy efficiencies of a CI (compression ignition) engine. Various exergy losses, exergy destruction and their ratios associated with the heat transfer through cooling water, radiation, exhaust gas, friction, and some uncounted exergy destruction are investigated. Apart from exergy loss due to heat transfer; the uncounted exergy destruction (due to combustion) also plays a major role in the system inefficiency. Based on the comparative assessment of the obtained results, it is concluded that a better combustion with less irreversibility is possible with the increase in O2 content in the fuel. Youcai Liang et al [15] found Oxygen enriched combustion (OEC) is potential to improve emissions, thermal efficiency and brake power output of diesel engine. The purpose of this investigation is to study whether it is feasible to apply water diesel emulsion to mitigate the increasing NOx caused by OEC with comparable BSFC and power output. Effect of OEC on particle size and number concentration was also analyzed in this paper

From the literature review , it is observed that, lot of work has been done to improve the performance and emissions using oxygen enriched air in diesel engine, studies on objective of optimization to determine the most suitable set of operating variables, with latest optimization techniques.. Hence, the main objective of the present research is to set up an experimental study the effects of environmental engine pollutant (Load and oxygen concentration ratio) on the performance (brake thermal efficiency and specific fuel consumption) and emission characteristics (hydro carbon emission, carbon monoxide emission, NOx emission and opacity) of the diesel engine, providing oxygen enriched air intake in the diesel engine, using response surface methodology (RSM)-based experimental design, and the other objective is to find the optimal values of oxygen concentration ratio with variable load, which would be resulting in improved performance with minimized emissions using the desirability approach.

## 2. MATERIALS AND METHODS

In this section, the detail about the engine, testing equipments, oxygen enrichment setup, RSM, and desirability approach are discussed.

## 2.1 Details of Engine and Testing Equipments

The engine selected for this experimental work is a single cylinder, constant speed diesel engine. The specification of the engine and testing equipments are given in Table 1.

## 2.2 Oxygen Enrichment Setup

Oxygen is supplied using oxygen cylinder to the air intake of the engine just before the mixing chamber where the mixing of air and oxygen is happening. A flow control valve was fitted to the oxygen cylinder and it was used to control the oxygen concentration from 21% to 27% by volume fraction. The oxygen concentration is measured with an Oxygen analyzer fitted between mixing chamber and inlet manifold of the engine. The natural atmospheric air is having oxygen concentration of 21% by volume. The flow control valve is operated and the oxygen value is set for 23%, 25% and 27% by volume in intake air

**Table 1: Specification of engine**

| S.No | Parameter | Details |
|---|---|---|
| 1 | Number of cylinders, strokes | Single cylinder, four stroke |
| 2 | Bore and Stroke | 80mm and 110mm |
| 3 | Power | 3.5 kW @ 1500rpm |
| 4 | Compression ratio | 17.5 |
| 5 | Type of cooling | Water cooling |
| 6 | Loading | Eddy current water cooled dynamometer |
| 7 | Measurement of CO, HC, $No_x$, $Co_2$ | AVL 444 gas analyzer |
| 8 | Measurement of smoke opacity | AVL 437 smoke meter |

## 2.3 Response Surface Methodology

Response surface methodology is a modern approach of collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. The most extensive applications of RSM are in the particular situations, where the several input variables greatly influence the performance and characteristic quality of the system. Thus, performance and characteristic is called the response. The Response surface methodology consists of the experimental plan for exploring the space of the process or independent variables, to develop the empirical statistical modeling for an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the values of the process variables that produce desirable values of the response.

Response surface methodology was used to model and analyze the response parameters to obtain the engine performance and characteristics. The design and analysis of experiment involved the following steps. The step one was the selection of the parameters that influence the performance and emission characteristics. In this study, the oxygen concentration ratio and load were considered as the input parameters. The oxygen concentration ratio (denoted by 'OCR') was varied at four levels in steps of two from 21% to 27%. The load (denoted by 'L') was varied from 0% to 100%. The advantage of using design of experiments is to evaluate the performance of the engine over the entire range of variation of OCR and other parameters with minimum number of experiments. The design matrix was selected based on the 2 level factor design of Response surface methodology (RSM) generated from the software ''Design Expert'' version 10 of stat ease, US, which contained 16 experimental runs as shown in Table 2. As per the run order, the experiments were conducted on the engine, and the responses were fed on the responses column.

## 2.4 Desirability Approach

The real-life problems require optimization with the multiple responses of interest. Techniques like overlying the contour plots for each response, constrained optimization problems, and desirability approach are found to have benefits like simplicity, availability in the software, and flexibility in weighting and giving importance for individual response. In the present work, RSM-based, desirability approach is used for the optimization of input parameters like OCR and load for the measured properties of responses (BTE, BSFC, CO, HC, CO2, NOx and smoke). The optimization analysis is carried out using Design Expert software, where each response is transformed to a dimensionless desirability value (d) and it ranges between d = 0, which suggests that the response is totally unacceptable and d = 1, which suggests that the response is more desirable. The goal of each response can be either maximum, minimum, target, in the range and/or equal to depending on the nature of the problem. The desirability of each response can be calculated by the following equations with respect to the goal of each response.

For a goal of minimum, di = 1 when Yi ≤ Lowi; di = 0 when Yi ≥ Highi and

$$\mathrm{di} = \left[\frac{\mathrm{High_i} - \mathrm{Y_i}}{\mathrm{High_i} - \mathrm{Low_i}}\right]^{\mathrm{wti}} \text{when Lowi < Yi < Highi}$$

For a goal of maximum, di = 0 when Yi ≤ Lowi; di = 1 when Yi ≥ Highi and

$$di = \left[\frac{Y_i - Low_i}{High_i - Low_i}\right]^{wti} \text{when Lowi < Yi < Highi}$$

For goal as target, di = 0 when Yi < Lowi; Yi ≥ Highi

$$di = \left[\frac{Y_i - Low_i}{T_i - Low_i}\right]^{wt1i} \text{when Lowi < Yi < Ti}$$

$$di = \left[\frac{Y_i - High_i}{T_i - High_i}\right]^{wt1i} \text{when Ti < Yi < Highi; and}$$

For the goal within the range, di = 1 when Lowi < Yi < Highi and di = 0.

**Table 2: Experimental Design Matrix**

| Run order | Load (%) | Oxygen Concentration Ratio (%) | BTE (%) | BSFC (kg/kw-hr) | HC (PPM) | CO (%) | NOx (PPM) | Opacity (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 80 | 23 | 31.975 | 0.2534 | 73.72 | 0.0251 | 1692.81 | 0.7986 |
| 2 | 40 | 25 | 24.1747 | 0.3372 | 41.98 | 0.0101 | 1944.44 | 0.3657 |
| 3 | 0 | 25 | 0 | 0.8 | 31.41 | 0.04 | 720.588 | 0.0537 |
| 4 | 100 | 21 | 33.5003 | 0.2488 | 93.27 | 0.0354 | 1258.17 | 0.9631 |
| 5 | 0 | 27 | 0 | 0.7977 | 31.1 | 0.03 | 789.22 | 0.0537 |
| 6 | 0 | 27 | 0 | 0.7977 | 31.1 | 0.03 | 789.22 | 0.0537 |
| 7 | 0 | 21 | 0 | 0.7977 | 54.8 | 0.0703 | 68.63 | 0.1477 |
| 8 | 60 | 27 | 30.3523 | 0.2744 | 40.06 | 0.0099 | 2973.86 | 0.5168 |
| 9 | 60 | 25 | 26.7 | 0.3069 | 65.38 | 0.0196 | 1727.12 | 0.7047 |
| 10 | 20 | 27 | 15.6503 | 0.5163 | 37.5 | 0.0198 | 1475.5 | 0.2014 |
| 11 | 100 | 27 | 32.8753 | 0.2442 | 55.13 | 0.0257 | 3088.24 | 0.8187 |
| 12 | 100 | 25 | 35.8757 | 0.2488 | 58.97 | 0.0251 | 2539.22 | 0.8187 |
| 13 | 60 | 25 | 26.7003 | 0.3069 | 65.38 | 0.0196 | 1727.12 | 0.7047 |
| 14 | 100 | 21 | 33.0003 | 0.2488 | 93.27 | 0.0354 | 1258.17 | 0.9631 |
| 15 | 20 | 23 | 14.775 | 0.5395 | 57.05 | 0.0492 | 892.16 | 0.208 |
| 16 | 100 | 25 | 35.8757 | 0.2488 | 58.97 | 0.0251 | 2539.22 | 0.8187 |

Here ‘‘i’’ indicates the response, ‘‘Y’’ the value of response, ‘‘Low’’ represents the lower limit of the response, ‘‘High’’ represents the upper limit of the response, ‘‘T’’ means the target value of the response, and ‘‘wt’’ indicates the weight of the response. The shape of the desirability function can be changed for each response by the weight field. Weights are used to give more emphasis to the lower/upper bounds. Weights can be ranged from 0.1 to 10; a weight greater than 1 gives more emphasis to the goal, weights less than 1 give less emphasis. When the weight value is equal to one, the desirability function varies in a linear mode. Solving of multiple response optimizations using the desirability app roach involves a technique of combining multiple responses into a dimensionless measure of performance called the overall desirability function. In the overall desirability objective function (D), each response can be assigned an importance (r), relative to the other responses. Importance varies from the least important value of 1, indicated by (+), the most important value of 5, indicated by (+++++). A maximum value of D indicates the more desirable and the best functions of the system, which is considered as the optimal solution. The optimum values of factors are determined from value of individual desired functions (d) that maximizes D [16].

## 3. EXPERIMENTAL SETUP AND TESTING

In this section the details of experimental setup and the procedure of testing are discussed in detail.

### 3.1 Experimental Setup

The experimental setup used in this research is demonstrated in Fig. 1. Oxygen enrichment setup is fitted to the intake of the engine. Exhaust gas analyzer was used to measure the emission values. Burettes were used to measure the volumetric fuel consumption rates of diesel. The exhaust gas temperature and cooling water outlet temperature were measured online by a K-type iron constant thermocouple.

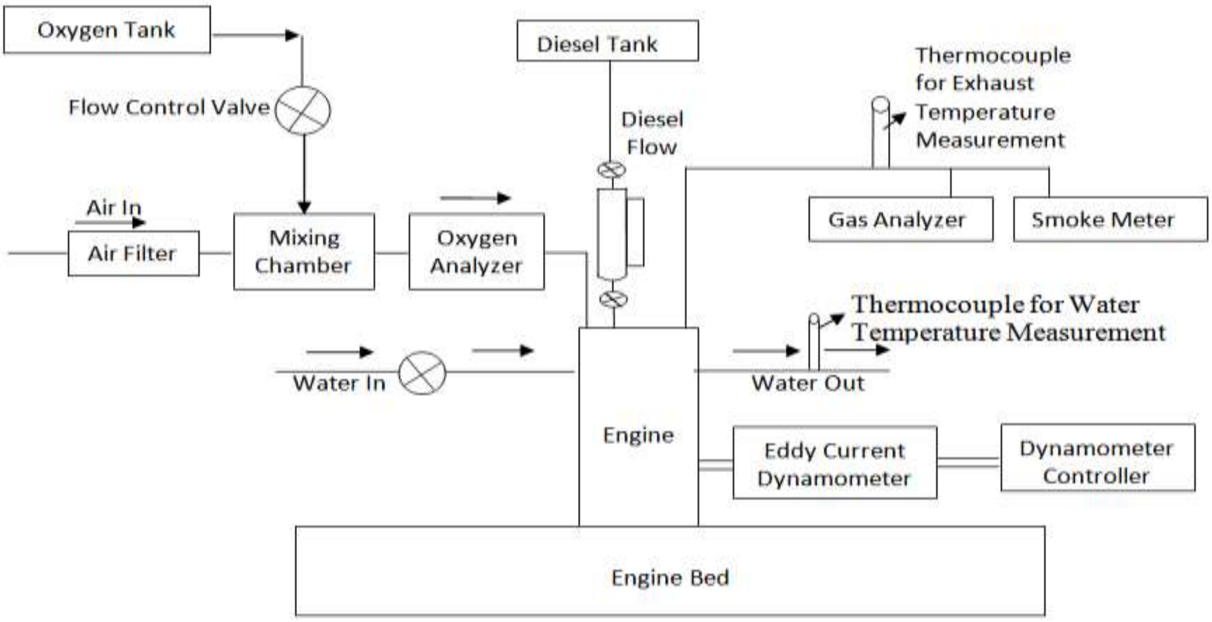


**Figure 1: Schematic of the Experimental Setup**

## 3.2 Testing

The experiments were carried out for different loads on the engine. The engine was run for 20 minutes to warm up. The quantities of fuel consumed at different loads and oxygen concentration ratios of the engine were measured. The intensity of opacity was measured by the light obscuration method in which the intensity of the light beam is reduced by opacity, which is a measure of opacity intensity. The carbon monoxide, hydrocarbons emissions were measured by Non-Dispersive Infra Red analyzer. The exhaust gases were allowed to pass through a water trap immersed in an ice bath to separate the condensed water so that only dry exhaust gas was allowed into the exhaust analyzer. Measurement of exhaust gas emissions and opacity were done by AVL gas analyzer and opacity meter. The readings were taken for diesel with different oxygen concentration ratios.

## 4. RESULTS AND DISCUSSION

In this section the various results obtained from design of experiment are discussed.

## 4.1 Analysis of the Model

The principal model analysis was based on the analysis of variance (ANOVA) which provides numerical information for the p value. The models found to be significant as the values of p were less than 0.05. The different models for the responses were developed in terms of actual factors and are given below as equations. (1) – (6).

BTE = +88.95051-1.74140* L-11.13171* OCR+0.19576* L * OCR-3.33456E-003* L2+0.46409* OCR2-3.05551E-004* L2* OCR-3.44508E003* L * OCR2+4.56647E-005* L3-6.44569E-003* OCR3 -------------- (1)

SFC = +0.21004-0.013512* L+0.049716* OCR-1.17421E-006* L * OCR+8.15952E-005* L2-1.05226E-003* OCR2 -------------- (2)

HC = +178.39041+0.28175* L-5.58839* OCR --------------- (3)

CO = +0.37511-2.11389E-003* L-0.019976* OCR+5.31004E-005* L * OCR+6.26722E-006* L2+2.65709E-004* OCR2 --------------- (4)

NOx = -2553.20085-35.01849* L+131.03381* OCR+2.16715* L * OCR --------------- (5)

Opacity = +0.53864+8.02225E-003* L-0.018188* OCR --------------- (6)

## 4.2 Evaluation of the Model

The stability of the models was validated using Analysis of variance (ANOVA). The output indicated that the model was significant with p values less than 0.0001. The reference limit for p was chosen as 0.05. The regression statistics goodness of fit (R2) and the goodness of prediction (Adjusted R2) are shown in Table 3 for all the responses. The R2 value indicates the total variability of response after considering the significant factors. The (adjusted R2) value indicates for the number of predictors in the model. Both the values indicate that, the model fits the data very well.

**Table 3: Response Surface Model Evaluation**

| Model | BTE | BSFC | HC | CO | $NO_x$ | Opacity |
|---|---|---|---|---|---|---|
| Mean | 16.9447 | 0.514727 | 55.57 | 0.029 | 1592.73 | 0.456813 |
| SD | 15.565 | 0.259293 | 6.64 | 4.513E-003 | 254.93 | 0.377483 |
| R | 0.9988 | 0 | 0.9033 | 0.9393 | 0.9304 | 0.9985 |
| Model degree | Cubic | Quadratic | Linear | Quadratic | 2FI | Linear |
| Adj. $R^2$ | 0.9970 | 0.9885 | 0.8884 | 0.9090 | 0.9130 | 0.9600 |
| Pred. $R^2$ | 0.9703 | 0.9829 | 0.8588 | 0.7962 | 0.8772 | 31.401 |

## 4.3 Engine Performance

Engine performance is measured interns of brake thermal efficiency and brake specific fuel consumption and the results of these are discussed here.

### 4.3.1 Brake Thermal Efficiency

BTE is calculated by following equation (7).

$$\mathrm{BTE} = \frac{\mathrm{BP}}{\mathrm{CV} \times \mathrm{TFC}} \times 100\,\% \qquad \text{--------------- (7)}$$

Where, BP is Brake power in W, CV= calorific value of fuel (43,350 kJ/kgK), and TFC is total fuel consumption in kg/s. The variation of BTE against oxygen concentration ratio and loads is shown in Figure 2. An increase in oxygen concentration increases the brake thermal efficiency due to change in thermodynamic properties of the mixture. The potential to convert thermal energy to work energy is increased due to oxygen availability. 7.9% increase in BTE is obtained for 25% OCR when compared with 21% OCR at 100% load.

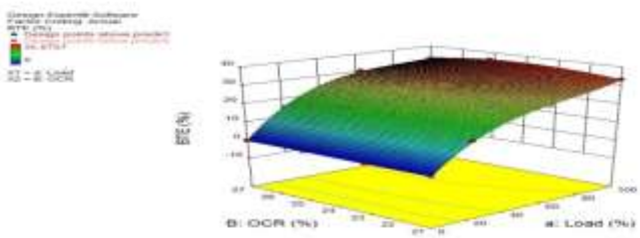

**Figure 2: BTE variations against oxygen concentration Ratio and Load**

### 4.3.2 Specific Fuel Consumption

SFC is calculated by following equation.

$$\mathrm{SFC} = \frac{\mathrm{VCC} \times \text{specific gravity of diesel} \times 3600}{\mathrm{t} \times 1000 \text{ X } \mathrm{BP}} \qquad \text{--------------- (7)}$$

Where VCC is volume of fuel consumption (10cc), S is specific gravity of fuel (0.833), t is Time for 10cc of fuel consumption (s) and BP is brake power. The variation of SFC against oxygen concentration ratio and loads is shown in Figure 3. An increase in oxygen concentration decreased the specific fuel consumption due to complete combustion because of additional oxygen. 16% decrease in SFC is obtained for 25% OCR when compared with 21% OCR at 60% load.

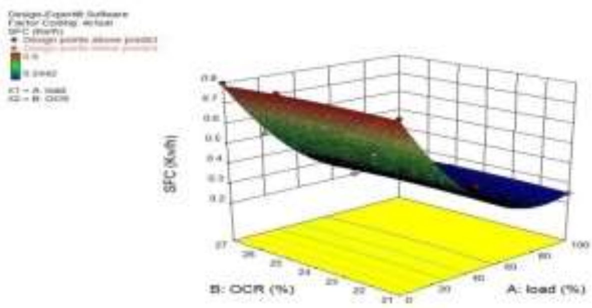

**Figure 3: SFC variations against oxygen concentration Ratio and Load**

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## 4.4 Engine Emissions

Engine emissions are measured interns of carbon monoxide, hydrocarbon, carbon dioxide, oxides of nitrogen and smoke and the results of these are discussed here.

### 4.4.1 Carbon Monoxide

The variation of CO against oxygen concentration ratio and loads is shown in Figure 4. The results showed that there is a significant decrease in CO emission with increase in oxygen concentration ratio. The results showed that the average CO emission decrease was 57%, 67%, 75%, 50%, 33% and 29% for 0%, 20%, 40%, 60%, 80% and 100% loads respectively

for 27% OCR when compared to 21% OCR. The extra oxygen present during combustion is the fact for the decrease in CO value.

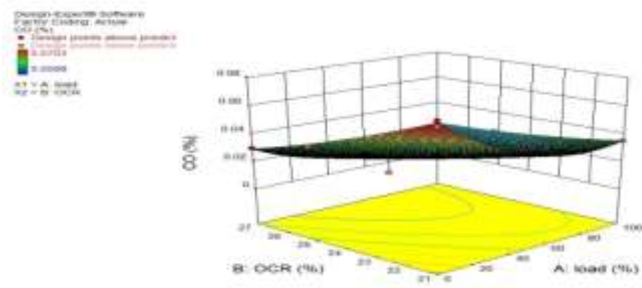

**Figure 4: CO variations against Oxygen Concentration Ratio and Load**

### 4.4.2 Hydrocarbon

The variation of HC against oxygen concentration ratio and loads is shown in Figure 5. The results showed that there is a significant decrease in HC emission with increase in oxygen concentration ratio. The results showed that the average CO emission decrease was 45%, 43%, 46%, 57%, 51% and 47% for 0%, 20%, 40%, 60%, 80% and 100% loads

respectively for 27% OCR when compared to 21% OCR. The more complete combustion is the fact for the decrease in CO value.

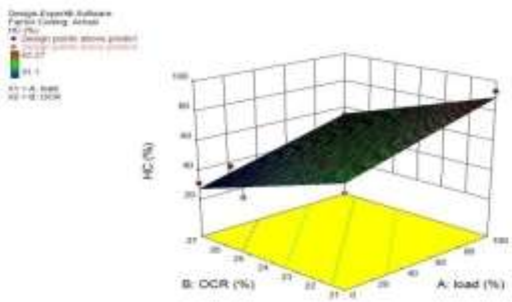

**Figure 5: HC variations against Oxygen Concentration Ratio and Load**

### 4.4.4 Oxides of Nitrogen

The variation of NOx against oxygen concentration ratio and loads is shown in Figure 6. The results showed that there is a significant increase in NOx emission with increase in oxygen concentration ratio. The results showed that the average NOx emission increase was 200% and 900%for 100% and 0% loads respectively for 27% OCR when compared to 21% OCR. The highest flame temperature is the fact for the increase in NOx value.

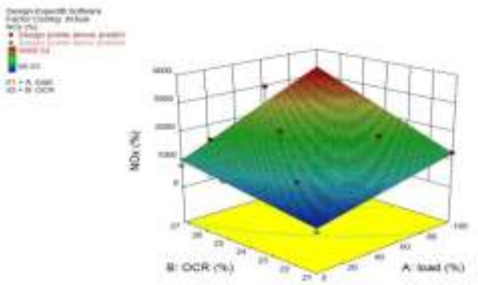

**Figure 6: NOx variations against Oxygen Concentration Ratio and Load**

### 4.4.5 Smoke

The variation of opacity against oxygen concentration ratio and loads is shown in Figure 7. The results showed that there is a significant decrease in opacity emission with increase in oxygen concentration ratio. The results showed that the average opacity emission decrease was 16% and 7%for 100% and 0% loads respectively for 27% OCR when compared to 21% OCR. The complete combustion is the fact for the decrease in NOx value.

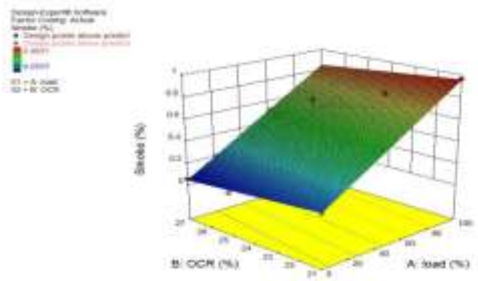

**Figure 7: Smoke variations against Oxygen Concentration Ratio and Load**

## 4.5 Optimization

The criteria for the optimization, such as the target set for each response for lower and upper limits used, weight used, and importance of the factors are presented in Table 4. In desirability-based approach, various best solutions were found out. The solution with high desirability was preferred. Maximum desirability of 0.678 was obtained at the following system parameters like 25.864% of OCR and 34.971% of load which could be considered as the optimum parameters for the test engine having 3.75 kW as rated power at 1,500 rpm.

**Table 4: Optimization criteria and desirability response**

| Source | Lower limits | Upper limits | Weight | | Importance | target |
|---|---|---|---|---|---|---|
| | | | Upper | Lower | | |
| Load (%) | 0 | 100 | 1 | 1 | 3 | In range |
| Oxygen Concentration Ratio (%) | 21 | 27 | 1 | 1 | 3 | In range |
| BTE (%) | 24.0361 | 31.2904 | 1 | 1 | 5 | Maximize |
| BSFC (kg/kwhr) | 0.233397 | 0.43571 | 1 | 1 | 5 | Minimize |
| CO (%) | 39.8973 | 53.1755 | 1 | 1 | 5 | Minimize |
| HC (PPM) | 0.00785888 | 0.0457677 | 1 | 1 | 5 | Minimize |
| NOx (PPM) | 1605.68 | 2225.8 | 1 | 1 | 5 | Minimize |
| Opacity (%) | 0.321669 | 0.770581 | 1 | 1 | 5 | Minimize |

### 4.5.1 Validation of optimized result

In order to validate the optimized result, the experiments were conducted thrice at the optimum system parameters. For the actual responses, the average of three measured results was calculated. Table 5, shows summarizes the average of experimental values, predicted values and the percentage of error. The validation results indicated that the model analysis was quite accurate as the error in prediction was at acceptable limit.

**Table 5: Comparison of actual and predicted values**

| S.No | Value | Load (%) | Oxygen concentration Ratio (%) | BTE (%) | SFC (kg/kwhr) | CO (%) | HC (PPM) | NOx (PPM) | Smoke (HSU) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Predicted | 40 | 23 | 24.0498 | 0.3372 | 59.62 | 0.0293 | 1464.05 | 0.3725 |
| 2 | Actual | 40 | 23 | 23.888355 | 0.385855 | 61.12744 | 0.030546 | 1063.615 | 0.441206 |
| 3 | Error | - | - | 0.161145 | -0.04865 | -1.50744 | -0.00125 | 400.435 | -0.06871 |

## 5. TOOL FOR PREDICTION OF PERFORMANCE AND EMISSIONS

Using the mathematical model, a tool is created using LabVIEW software and is shown in figure 8. This tool is useful for obtaining performance results when engine input parameters are given as input. It is easy to install this tool in any operating system and doesn't need any special skills for operating the tool.


**Figure 8: Tool for Predicting Engine Output Parameters**

## 6. CONCLUSION

Based on the results, the following conclusions were arrived in terms of engine performance and exhaust emission characteristics. Oxygen enrichment can be suitable method of increasing BTE and minimizing the CO, HC and opacity in a diesel engine. The design of experiments is very much helpful to design the experiment and the statistical analysis helped to identify the significant parameters which are most influencing on the performance and emission characteristics. From this experimental design considerably reduced the time required by minimizing the number of experiments to be performed and provided statistically proven models for all response. It is clear from this research that BTE and NOx have been increased when oxygen enrichment is increased from 21 to 27%. Beside, CO, HC, and opacity emissions have been deceased when increasing oxygen enrichment from 21 to 27% in the air intake system. Desirability approach of the Response surface methodology was found to be the simplest and efficient optimization technique. A high desirability of 0.678 was obtained at the optimum engine load of 34.971% and oxygen concentration ratio of 25.864%, where the values of the BTE, BSFC, HC, CO, NOx and smoke were found to be 23.7752 %, 0.413 kg/kW-hr, 37.566ppm, 0.018%, 1930.431ppm and 0.323% respectively. The oxygen enrichment decreases the pollutants of diesel engine and saves the environment in a better way.

## NOMENCLATURE

| | |
|---|---|
| P | Power |
| RSM | Response Surface Methodology |
| OCR | Oxygen Concentration Ratio |
| L | Load |
| BTE | Brake Thermal Efficiency |
| BSFC | Specific Fuel Consumption |
| CO | Carbon Monoxide |
| $NO_x$ | Oxides of Nitrogen |
| O | Opacity |

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