

# **OPTIMIZATION OF DIESEL ENGINE PERFORMANCE USING BERGAMOT OIL METHYL ESTER - GREY RELATIONAL ANALYSIS APPROACH**

**Submitted for partial fulfilment of the requirements for the award of  
Bachelor of Technology in  
Mechanical Engineering**

**By**

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**INSTITUTE OF SCIENCE AND TECHNOLOGY  
(DEEMED TO BE UNIVERSITY)**

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**DEPARTMENT OF MECHANICAL ENGINEERING**

**BONAFIDE CERTIFICATE**

This is to certify that this Project report is the bonafide work of **KARTHICK. K (37150091)** and **KARTHIKEYAN. M (37150093)** who carried out the project entitled on **optimization of diesel engine performance using bergamot oil methyl ester –grey relational analysis approach** under our supervision from September 2020 to March 2021.

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Submitted for Viva voice Examination held on \_\_\_\_\_

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## DECLARATION

We **KARTHICK. K (37150091)** and **KARTHIKEYAN. M (37150093)** hereby declare that the Project report entitled **optimization of diesel engine performance using bergamot oil methyl ester - grey relational analysis approach** done under the guidance of **Dr.GANESAN M.E., Ph.D., Department of Mechanical Engineering** is submitted in partial fulfillment of the requirements for the award of **Bachelor of Technology in Mechanical Engineering.**

1.

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2.

PLACE :

SIGNATURE OF THE CANDIDATES

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We would like to express our gratitude to the Board of Management of the **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** for their support in completing this project successfully.

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Last but not least, we want to express our sincere gratitude to our loving parents, family members, and friends, who have all helped me finish my project and earn my degree.

## **ABSTRACT**

If the world's population grows, the supply of fossil fuels declines, making gasoline and diesel more scarce. As a result, this generation considers or pushes toward alternatives to fossil fuels. As a result, biodiesel would be used as a substitute for fossil fuels. Many researchers and scientists claim that biodiesel can have the same properties as gasoline and diesel, but with fewer toxicity and emissions. Bio-diesel is a kind of diesel derived from plants, vegetables, or animals that contains a long-chain fatty acid ester. It is produced by reacting a lipid, such as vegetable oil, with alcohol to produce methyl and propyl esters. Mono-acyl esters of long fatty acid are the chemical name for it. ANOVA was used to examine the relative effect of control factors on production reactions, and the relative influence of load was found to be the highest. The grey relational analysis converts multiple objective optimisation problems into single objective optimisation problems with the help of a grey relational grade and appropriate weighting variables. The Grey-Taguchi method offers the best factor environment. As a consequence, the most efficient input parameters for diesel engines have been identified.

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## LIST OF ABBREVIATIONS

|                 |   |                              |
|-----------------|---|------------------------------|
| ANOVA           | – | Analysis of Variance         |
| B100            | – | Biodiesel                    |
| BP              | – | Brake Power                  |
| BTE             | – | Brake Thermal Efficiency     |
| CI              | – | Compressed Engine            |
| CO              | – | Carbon Monoxide              |
| CO <sub>2</sub> | – | Carbon Dioxide               |
| E310            | – | Propyl Gallate (Antioxidant) |
| GRC             | – | Grey Relational Coefficient  |
| GRG             | – | Grey Relational Grade        |
| HC              | – | Hydrocarbon                  |
| IP              | – | Injection Pressure           |
| NOX             | – | Nitrogen Oxides              |
| O <sub>2</sub>  | – | Oxygen                       |
| PPM             | – | Parts per Million            |
| SFC             | – | Specific Fuel Consumption    |
| SNR             | – | Signal to Noise Ratio        |
| SO <sub>2</sub> | – | Sulphur Dioxide              |

# CHAPTER 1

## INTRODUCTION

Engine which we are used for the performance is compression ignition engine otherwise known as Diesel engine, where the name is derived from "**RUDOLF DIESEL**" who invented the Diesel. In a Diesel engine, which is achieved by higher temperature make by squeezing air in the cylinder during the period of time entry of the fuel. There is a inflated demand for diesel engine in factory - made, agronomy, automobile sector. Benefits of this engine than petrol engines are fewer maintenance, greater thermal efficiency, price will be less and so on. As the population still increasing, the sources of Fossil fuels are decreases, which the petrol and diesel availability becomes less. So this generation thinks or moves for alternate of fossil fuel. Therefore the alternate for fossil fuel will be biodiesel many researchers and scientists are identifying that biodiesel will have same properties with less pollution and emission than gasoline and diesel.

Bio-diesel is a diesel which we get from plants, vegetables or animals which it has long-chain fatty acid ester. It is made by chemical reaction lipid such as vegetable oil and so on with alcohol producing methyl, propyl ester chemically it is known as Mono-alcyl esters of long fatty acid which comes from Renewable sources (Natural sources).

**Benefits of biodiesel** are it is Renewable, Incredibly safe, Ready to use, which extend, engine life span, where environmental protection agency has certified that it produced 11%lower carbon monoxide and as much as 10 %lower particulate matter than fossil fuel, compared to gasoline and diesel.

For this project we have add bergomet oil with diesel for the production of bio-diesel to optimize the diesel engine performance and emission parameter.

Biodiesel is a liquid biofuel made from vegetable oils or animal fats and an alcohol that can be used alone or in combination with diesel engines. Diesel oil is added to the mix. Biodiesel is described as a mixture of long-chain monoalkylic esters from plants. Fatty acids derived from renewable resources that will be used in diesel engines. Blends with diesel fuel are indicated as “Bx”, where “x” is the percentage of biodiesel in the blend. For instance, “B5” indicates a blend with 5% biodiesel and 95% diesel fuel; in consequence, B100 indicates pure biodiesel.

## **1.1 ADVANTAGES OF BIODIESEL**

- Renewable fuel derived from plant oils or animal fats.
- In contrast to diesel fuel, it has a low toxicity.
- Degrades faster than diesel fuel, reducing the environmental impact of biofuel spills.
- Reduced contaminant emissions include carbon monoxide, particulate matter, polycyclic aromatic hydrocarbons, and aldehydes.
- Reduced health risk as a result of lower emissions of carcinogenic substances.
- There are no sulphur dioxide (SO<sub>2</sub>) emissions.
- Greater flash point (100C minimum).
- May be blended in some proportion with diesel fuel; Both fuels may be mixed during vehicle fuel supply.
- Excellent lubricant properties.
- It is the only substitute fuel that can be used without modification in a traditional diesel engine.
- As raw materials, used cooking oils and fat residues from meat processing can be used.

## **1.2 DISADVANTAGES OF BIODIESEL**

- There is a marginal rise in fuel use due to biodiesel's lower calorific value.
- The emissions of nitrous oxide (NO<sub>x</sub>) are significantly higher than those of diesel fuel. It has a lower freezing point than gasoline.
- This could be unpleasant in the winter. Since it is less stable than gasoline, it is not recommended for long-term storage (more than six months).
- Biodiesel can not be used for more than a few months.
- It can degrade plastic and natural rubber gaskets and hoses when used in its pure form.

## **1.3 RAW MATERIALS FOR BIODIESEL PRODUCTION**

The raw materials used to produce biodiesel are vegetable oils, animal fats, and short-chain alcohols. Rapeseed (primarily in European Union countries), soybean (Argentina and the United States of America), palm (Asian and Central American countries), and sunflower are the most widely used oils for biodiesel production around the world. Other oils used include peanut, linseed, safflower, used vegetable oils, and animal fats. Methanol is the most widely used alcohol.

Non-edible vegetable oils have been studied for several years with positive results because cost is a major factor in biodiesel production and distribution (due to oil prices).

Apart from the cost savings, another undeniable advantage of using non-edible oils for biodiesel production is that no food is wasted.

These and other factors have helped the medium and large-scale production of biodiesel. In several countries, castor oil, tung oil, cotton oil, and other non-edible oils were used in trials. Since they are solid, they must be handled first;

additionally, highly acidic grease from beef, pork, poultry, and fish is an acceptable substitute.

Microalgae are a very important choice for potential biodiesel production because of their high oil yield; however, only a few species are suitable for biofuel production.

#### **1.4 PHYSICO-CHEMICAL PROPERTIES OF DIESEL FUELS**

Since automobiles and their engines are designed to operate in a wide range of environments, achieving the required performance and reliability is dependent on both technological factors relevant to their manufacture and the nature of the fuels used. As a consequence, the fuels' physico-chemical characteristics must be presented. They have an influence on the engine's output. Furthermore, given the vast number of fuels that can be made by combining different combustibles, understanding their physico-chemical properties is critical.

#### **1.5 VISCOSITY**

According to the international standard, viscosity is a measure of resistance to liquid flow caused by internal friction of one part of a fluid flowing over another under the force of gravity. This is a significant property since it affects how fuel behaves. Since ambient temperature influences viscosity, steps must be taken to prevent the engine's output from degrading, such as attempting to start the engine at very low ambient temperatures due to the higher viscosity. Owing to a lack of fuel, the engine could have difficulty starting.

Larger droplet sizes, weaker atomization and vaporisation of fuel In addition, high viscosity can reduce fuel flow rates, resulting in inadequate fuel delivery. a source of power A very high viscosity can also cause pump distortion. Finally, high fuel viscosity contributes to low overall combustion, increased emissions, and increased costs. Oil diluting.

## **1.6 DEPENDING ON THE MEASUREMENT METHOD, THERE ARE TWO TYPES OF VISCOSITY**

The ISU (International System of Units) unit of dynamic or absolute ( ) viscosity is  $[\text{Ns} / \text{m}^2]$ . Dynamic viscosity is expressed in  $\text{P} = \text{Poise}$  in the CGS system (centimetre, gramme, second).

## **1.7 DENSITY**

A substance's density, or more generally, volumetric mass density, is its mass per unit volume. Another important factor influencing engine efficiency is fuel density. Since fuel is metered by volume rather than mass, the density of the fuel determines how much fuel is injected. As a result, fuel density affects the air-fuel ratio and energy content inside the combustion chamber. Density rises as the ambient temperature falls; as a result, it, like viscosity, influences engine cold starting efficiency. The density measurement unit is  $\text{kg}/\text{m}^3$ .

## **1.8 CETANE NUMBER**

Cetane Number (CN) is the primary indicator of the auto-ignition and combustion efficiency characteristics of diesel engine gasoline. It has an effect on cold starting, combustion stability, and noise. A higher CN reduces engine cranking time (the time before the engine starts) by reducing the ignition delay.

## **1.9 EVAPORATION CHARACTERISTICS**

Evaporation properties affect spray structure and air–fuel mixture preparation under varying engine load conditions. The vapour pressure and distillation curves, which are influenced by intermolecular interactions, are used to define the volatility characteristics. 11 The Distillation Curve (DC) shows how much fuel boils off at a given temperature. The curve is divided into three sections:

- (1) Since only the light fractions of the fuel boil in the beginning, the first region is known as the light end; it affects start capacity and is generally defined by the temperature at which 10% of the fuel has boiled (T10).

- (2) the region around the 50% evaporated stage, denoted by the T50;
- (3) the heavy end (i.e., boiling of the heavier fuel fractions), denoted by the T90 or T95 and has gained the most attention in terms of its effect on tailpipe emissions.

### **1.10 FLASH POINT CLOSED CUP**

The flash point is the lowest temperature at which a fuel will ignite (flash) when an ignition source is applied under specific conditions (FP). It's used to categorise transportation fuels. Minimum flash point temperatures are needed, as is storage based on danger level. to ensure proper fuel handling and safety Temperature has an opposite relationship with flash point.

### **1.11 COLD FLOW CHARACTERISTICS**

Cold flow characteristics are one of the most fundamental quality parameters for compression ignition engine fuels, and they are mainly determined by:

- (1) fuel distillation range, especially the light-end volatility;
- (2) hydrocarbon composition: paraffin, naphthene, aromatics content;
- (3) The application of cold flow additives.

The mechanism of cold flow properties is as follows: during low-temperature engine operation, fuel gelling occurs, resulting in crystallisation of liquid molecules. In order for crystallisation to occur, the liquid molecules must generate heat. The strong intermolecular force of interaction produces a considerable amount of thermodynamic force. This is an excellent example. Thermodynamic force is produced when the temperature of a liquid is reduced to a certain point. Fuel crystallisation during the thawing stage can result in "fuel starvation" and loss of operability. Solidified content causes issues by clogging fuel pipes, the fuel pump, filters, and injectors.

The low-temperature operability of diesel engines is defined by three fuel parameters: Cloud Point (CP), Cold Filter Plugging Point (CFPP), and Pour Point (PP).

The following parameters can be specified when the liquid fuel is cooled: The CFPP is the lowest temperature at which a given volume of diesel engine fuel passes through a standardised filtration device in a given period of time. The Low Temperature Flow Test (LTFT) was developed specifically for the United States and Canada to forecast how Diesel engine fuels can perform well at low temperatures. The LTFT abbreviation stands for "slow cooling test." To go with the wind, PP is the lowest temperature at which the fuel will stop burning, and it is more extreme than CFPP. The cold flow properties of diesel engine fuel must be determined based on the seasonal and climatic conditions in the area where the fuel will be used. The temperature at which a clear liquid product starts to cloud is defined as follows: The temperature at which a clear liquid substance becomes cloudy, i.e. when stable particles become unstable, is denoted by CP (alkane crystals and microcrystals of ice).

## **1.12 COLD FLOW LIMITS**

The cold flow output of diesel fuel can be defined using Cloud Point, CFPP (with a maximum delta between CFPP and Cloud Point), or LTFT.

- a) When using Cloud Point (only) or LTFT, the maximum permissible temperature should be no higher than the lowest predicted ambient temperature.
- b) If CFPP is used to forecast cold flow, the maximum allowable CFPP temperature should be set to be equal to or lower than the lowest predicted ambient temperature. The Cloud Point should be no more than 10°C above the CFPP stated in this case.

### **1.13 WATER CONTENT**

The fuel should be clear and free of water, which can clog fuel filters at low temperatures and cause engine fuel starvation. Water hastens oxidation, increases corrosivity, and encourages microbial development. The water content unit may be [mg/kg].

### **1.14 BERGOMOT OIL**

In the citrus fruit processing industry, the seeds are considered production waste. Although they account for just a small portion of the total weight of the fruit (3-5%), they produce an oily fraction that can be used for a number of purposes. Bergomet, also known as "Citrus bergamia Risso," is a citrus fruit in the Rutaceae family and Citrus genus. Bergomet is grown mainly in the Italian province of Reggio Calabria. Calabria's cultivators include Castagnaro, Femminello, and Fantastico. Fantastico cultivator now accounts for 90% of trees (Dugo et al., 1087). Bergomet is a form of jam that can also be used for medicinal purposes.

Basic oils are used in the fragrance industry (Ricci and Rovesti 1979; Pojana et al., 1994). Because of its bitter flavour, bergamot juice is generally unsuitable for use in the food industry. Citrus seed oil is suitable for use in food due to its chemical and physical properties (Ramadan and Morsel 2002). Numerous reports on citrus seed oil have been published in peer-reviewed journals. The bulk of the study focuses on quantitative fatty acid analysis (French, 1962; Habib et al., 1986; Saidani et al., 2004; Anwar et al., 2008).

A food-grade oil's consistency is determined by its fatty acid profile, specifically the ratio of saturated to unsaturated fatty acids.

Unsaturated fats are further graded as omega, w-9, which are non-essential, and w-3 and w-6, which are essential fatty acids that the human body cannot synthesise and must be obtained by diet (Ristic and Ristic 2003). Linoleic acid is present in all vegetable oils and is abundant in many of them, including sunflower seeds, but also corn oil, soybean oil, and, to a lesser extent, other oils. Linoleic acid is an essential fatty acid that is part of the w-6 fatty acid family. Due to

their semi-drying nature, the seeds of the Bergomot fruit, which are actually considered waste, may not only be a reliable source of edible oil (cooking oil, salad dressing, or margarine), but they may also have industrial applications. This study looked at the chemical and physical composition of Bergomot oil seed derived from three different cultivates to see whether there were any differences in composition.

### **1.15 ANTIOXIDANT**

Colorimetric, liquid chromatography (LC), and gas chromatography (GC) are the most popular methods for determining antioxidants. The AOAC's Method 965.28 defines qualitative colour tests for the detection of propyl gallate (PG), nordihydroguaiaretic acid (NDGA), butylated hydroxyanisole (BHA), and butylated hydroxytoluene (BHT). Following solvent and aqueous extractions, PG turns pink in ammonia solution, NDGA turns blue in barium hydroxide, BHA turns red–purple in Ehrlich reagent (diazobenzene sulfonic acid), and BHT turns pink to red in chloroform in the presence of dianisidine (3,3'-dimethoxybenzidine) and sodium nitrite.

Here in this project we have add "**PROPYL GALLATE**" as an **Antioxidants**.

**Propyl gallate**, also known as propyl 3,4,5-trihydroxybenzoate, is an ester formed when gallic acid and propanol are combined. To avoid oxidation, this antioxidant has been applied to foods containing oils and fats since 1948. 1st It has the E number E310 and is used as a food additive. Propyl gallate, also known as propyl 3,4,5-trihydroxybenzoate, is an ester formed when gallic acid and propanol are combined. Consonant

### ***Uses***

Propyl gallate is used to protect oils and fats in products from oxidation; it is used in foods, cosmetics, hair products, adhesives, and lubricants.

It is used as a triplet state quencher and an antioxidant in fluorescence microscopy.

**Table 1.1 Properties**

|                  |                                                |
|------------------|------------------------------------------------|
| Chemical formula | C <sub>10</sub> H <sub>12</sub> O <sub>5</sub> |
| Molar mass       | 212.20 g/mol                                   |
| Appearance       | White crystalline powder                       |
| Melting point    | 150 °C (302 °F; 423 K)                         |
| Boiling point    | Decomposes                                     |

## CHAPTER 2

### LITERATURE SURVEY

1. **Sureshbabu Yessian and P. Ashoka Varthanan** said that Taguchi has been used very efficiently in the optimization of performance and emissions using GRA. Characteristics of an IC-type piston coated copper-chromium-zirconium alloy. The three parameter improve performance and reduce emissions are identified as Fuel, Load and Speed. Cotton seed oil blended together diesel is used as a fuel and the results are compared to pure diesel. Experiments are conducted on the basis of the L9 orthogonal array and engine parameters are optimised through the Taguchi-GRA experimental design. Seven responses such as BP, BTh, Torque, SFC, CO HC and NOX for coated and uncoated engines have been identified. **Braking thermal efficiency (BTh) of copper chromium and zirconium coated engines improved marginally by 13.33 per cent and CO, while HC emissions decreased significantly by 98.59 per cent and 33.33 per cent respectively. Instead of a diesel-powered engine, cotton seed oil-mixed diesel (B20) fuel-powered coated engine produces better results, so cotton seed oil-bio diesel can be used as an alternative fuel to control emissions such as CO, HC of a diesel engine.**
2. **Goutam Pohit and Dipten Misra** told that the engine performance and emission characteristics of Karanja methyl ester blended with diesel fuel were performed on a variable compression diesel engine. In order to find the optimal response of the process through a limited number of experiments, the application of the Taguchi method in combination with a grey relational analysis was used to solve a multiple response optimization problem. Using grey relational grade and signal-to-noise

ratio as a performance index, a specific combination of input parameters was predicted to achieve optimum response characteristics. It was observed that a mixture of fifty percent was most suitable for use in diesel engines. The final finding of the experimental study was validated with the result of the actual experimentation. It was concluded that **the B50 blend was found to be the most suitable blend for diesel engines without significantly affecting engine performance and emission characteristics, the corresponding compression ratio and engine load being 17 and 80 percent respectively.**

3. **J.L. Lin , C.L. L in** said that a new approach for optimising the process of electrical discharge machining (EDM) with multiple performance characteristics based on an orthogonal array with a grey relational analysis has been studied. The grey relational grade obtained from the grey relational analysis is used to solve the EDM process with multiple performance characteristics. Optimal machining parameters can then be determined by the grey relational grade as the performance index. In this study, the parameters for machining Workpiece polarity, time pulse, duty factor, open discharge voltage, discharge current and dielectric fluid are optimised. With regard to the multiple performance characteristics. The use of the orthogonal array with a grey relational analysis to optimise the edm process with multiple performance characteristics has been reported in this paper. Gray relational analysis of the experimental results of electrode wear ratio, material removal rate and surface roughness can convert optimization of multiple performance characteristics into optimization of a single performance characteristic called Gray relational grade. As a result, the **optimization of complex multiple performance characteristics can be greatly simplified through this approach. The performance characteristics of the edm process, such as material removal rate, surface roughness and electrode wear ratio, are shown to be improved together using the method proposed in this study.**

4. **D. Yuvarajan, J. Ravikumar and M. Dinesh Babu** said that the objective of their present work is to optimise smoke and NO<sub>x</sub> emissions simultaneously in a diesel engine fuelled with stationary diesel-oxygenate blends using the Gray-based Taguchi method. Experiments were carried out using the Design of Experiments (DOE) method and tests were conducted on the basis of the Taguchi L9 orthogonal array. The effects of three parameters, namely the oxygen content of additives, the oxygen content of diesel and the varying timing of injections, were investigated. Experimental pathways were conducted by blending the various oxygenates chosen in different proportions with diesel and injection timing. The signal-to-noise (S/N) ratio of Taguchi was determined on the basis of its performance characteristics. Gray relational grade was obtained from the ratio S/N using a grey relational analysis (GRA). The individual effects of factors are estimated using variance analysis (ANOVA). The results of the experiments show that Diglyme blended with 10% diesel and injected at -21° crank angle is the optimum combination for the simultaneous reduction of smoke and NO<sub>x</sub> with a less significant impact on performance. **This combination shows a smoke reduction of 28.33 per cent with a NO<sub>x</sub> emission reduction of 17.4 per cent at the same time as the best possible performance increase of 6.7 per cent compared to diesel. The combination of the parametric design of GRA and Taguchi can be used effectively to obtain an optimal combination of the parameters chosen. Experimental results have also shown that this approach can improve the response variables effectively.**
5. **Mohd Muqeem et al.** told that Diesel engines can produce more efficient power with lower exhaust emissions when operated at optimum input parameter settings. To achieve this objective, the current research work aimed at optimising the input parameters of diesel engines leading to optimum performance and exhaust emissions. In order to achieve the objective of improving diesel engine performance and exhaust emissions, the study considered four input parameters. Five different levels of each input parameter have been taken. Four response variables were

recorded under no-load, half-load and full-load conditions. Experiments were performed randomly using the selected Taguchi L25 orthogonal array. The data was analysed using the Gray Relationship Analysis (GRA) and the main component analysis (PCA). The results of current research work provide optimum input parameters for the no-load, half-load and full-load conditions of diesel engines. Engines produce more efficient power with low exhaust emissions when operated at these optimum settings. **The results of the study presented in this article will be of considerable interest to diesel-engine-related researchers and professionals.**Value/Originality It appears from the literature review that only a few researchers have conducted studies on the optimization of the input parameters of diesel engines to improve their performance or exhaust emissions. Although a few studies have been reported on the optimization of the compression ratio (CR), fuel injection timing (FIT), fuel injection pressure and air pressure (AP), no work has been carried out on the optimization of turbocharged air temperatures and pressures.

6. **Ganesan Subbiah et al.** said that the present investigation focuses on an innovative method to improve efficiency by reducing fuel consumption and improving the combustion of nanoparticles and distilled lime vapour. Lime steam distilled oil is obtained from the Citrus aurantifolia peel. The characteristics of diesel engines using diesel as a fuel are taken as a benchmark and the combination of nanoparticle cerium oxide and diesel together with lime steam distilled oil will be compared with varying injection pressures. **Gray Relationship Analysis focuses on the objective of "optimising a response that is influenced by a number of independent variables"**. Homogeneous combustion catalysts are those additives which are homogeneously dissolved into diesel fuels to play a catalytic role during the combustion process of the engine. The Taguchi method is used to select an orthogonal array and a number of experiments. **The GRA coefficient is used to calculate the rank and is calculated on the basis of the GRA grade value. Analysis of**

**variance is used to calculate the percentage of contribution for the Gray Relationship Analysis.**

7. **Shakti Prakash Jena et al.** told that this study, the performance and emission characteristics of the diesel engine when fueled with biodiesel blends are optimised. Here, the effects of load, compression ratio and blending of brake thermal efficiency (BTE) and nitrogen oxides (NO<sub>x</sub>) were statistically investigated using the Taguchi method. Each input parameter is examined at four different levels. The results showed that BTE and NO<sub>x</sub> had reached their optimum values when the load was at the highest level, but for the other two input parameters, the optimal values of the output reactions were at different levels. Thus, the Gray Relationship Analysis accompanying the Taguchi method was used to reduce variations. The L16 orthogonal array was performed. After that, the experimental results were normalised using a grey relational analysis. Then, from the normalised data, the deviation sequence was obtained, and then the grey relational coefficients were obtained for each output response from the deviation sequence, and then the grey relational grade was determined. **The optimal factor setting was found to be 100 percent load, B20 blend and 17.5 compression ratio (CR). At last, the relative contribution of the control factors was determined by the use of ANOVA and the load was found to be the most influential factor.**
8. **S. Ganesan, J. Senthil Kumar and J. Hemanandh** said that the diesel engine is the primary source of fuel consumed worldwide. Diesel is expected to be a fossil fuel by 2050. Diesel has been found to be more reliable, durable and efficient. Bio diesel like lemon grass oil can play a vital role in this situation. Blends of diesel with biodiesel are expected to provide improved efficiency and emission characteristics. The addition of nanoparticles such as cerium oxide can make biodiesel more efficient. The performance of the diesel engine depends on various parameters such as fuel quantity injected, fuel injection timing, fuel injection pressure, combustion chamber and nozzle shape and size, fuel spray pattern, air

swirl, etc. This study deals with the impact of Ceo2 and compression ratio (C.R) on diesel engine performance. In the experimental study, different blends of biodiesel are tested at different compression ratios. The optimization techniques are applied to the results obtained and thus verified. This study shows that biodiesel is going to be the natural choice for our future transport fuel. The above combination of experience and reasoning makes it possible to draw some conclusions about biodiesel as an automotive fuel, particularly in developing countries such as India. The following facts have been established in the present work. **From the above study, the multi-response parameters (Engine Performance and Emission Study) are optimised using a grey relational analysis and converted into a single response. Then we used the Taguchi methodology to analyse the experimental data.**

9. **Apurba Pathaka, P.K.Choudhury and R.K. Duttac** told that the economy and exhaust emissions of automobiles have become the cause of concern these days due to the depletion of non-renewable energy sources on a global scale and to global warming. This paper involves the multi-objective optimization of the process parameters of the VCR Petrol Engine to obtain a minimum level of Hydrocarbon (HC) and Carbon Monoxide (CO) emissions in the exhaust and Brake specific fuel consumption (BSFC). Control parameters were selected as the compression ratio, the spark ratio. Advances, loads, air-fuel ratios (in terms of number of rotations of the air screw) and fuel knocking trends (in terms of octane rating of fuel). Experiments were conducted using the Taguchi orthogonal array L27 for the five control parameters at three operating levels each. Multi-objective optimization was performed using Gray Relational Analysis (GRA) to determine the optimal solution. Variance analysis (ANOVA) was performed to determine the significant and contributing control parameter. The interaction of factors was also considered in the study. The optimum level of the control parameters is 10:1 for the compression ratio, 200 for the spark Advance, 1.2 kW for the load, 1 for the air screw and 1 for the fuel having a knocking tendency. From the classification of the process parameters, it has been shown that

the load is the most dominant factor in the output response followed by the compression ratio and the spark advance. **ANOVA has shown that the HC emission compression ratio is the most significant factor followed by the advance of the spark. In the case of BSFC, the load was the most significant factor followed by the compression ratio, while in the case of CO emission, the number of air screw turns was the only significant factor.**

10. **M. Gul et al.** said that the work is carried out by L9 Orthogonal Array (OA) of the Taguchi design in order to obtain an optimum combination of fuel nature, engine speed and load for the DI-CI diesel engine that is alternatively fuelled with waste cooking oil (WCO) based on pure biodiesel (B100) and a 20% blend of biodiesel with pure diesel (B20) with the aim of achieving a maximum reduction in smoke and NOx emissions and improving the efficiency of the process. The optimal input parameters (fuel as B100, speed as 2300 rpm and load as 100 percent) were specified in the Gray Relationship Analysis in such a way that the preferred output results were successfully achieved. In addition, analysis of the variance (ANOVA) technique has shown that the nature of the fuel is the major leading factor with a 44.28 per cent impact on the output parameters. **The experimental and ANN simulated results of the predicted optimal combination ensured significant improvements in the output response factors, thus validating the use of the Gray Taguchi method to reduce emissions and improve combustion and simultaneous performance.**
11. **Hussain M, Peethambaran K and Ushakumari E** said that this paper presents an experimental study that includes the use of a grey relational analysis to determine the optimum factor level to obtain the optimum multi-performance characteristics of a diesel engine with different low-percentage chicken waste biodiesel-diesel mixtures. Gray relational analysis is used for data analysis and four factors were considered at four levels, namely low-percentage chicken waste biodiesel-diesel blend, compression ratio, timing of injection and injection pressure. The L16

orthogonal array was used to collect data for various engine performance related reactions under constant engine loads. The results of the confirmatory tests showed good agreement with the expected quantity. **The results of the study showed that the combination of a blend consisting of 10% chicken waste biodiesel (B10), a compression ratio of 18, an injection pressure of 220 bar and an injection time of 19° bTDC produces the maximum multiple performance of the diesel engine.**

12. **Mohd Muqeem et al.** said that the aim of his paper is to optimise the input parameters of the diesel engine with respect to the emission of hydrocarbons and smoke opacity through experimentation and the Taguchi approach. Four parameters, namely the compression ratio, fuel injection timing, air temperature and air pressure, varied at five different levels and recorded their effect on the emission of hydrocarbons and smoke opacity under no load, half load and full load conditions. Signal-to-noise ratio, analysis of means, and analysis of variance were used to find the best combination of control/input parameters that led to the best values of output parameters/response variables. **Confirmation tests were carried out to check the validity of the results, which revealed a good agreement between the predicted and the experimental values of the response variables at the optimum combination of the input parameters.**

13. **Dr. Tushar M Patel et al.** said that the Karanja, which is one of the source of biodiesel. In this study, blend of Karanja biodiesel is in the proportion 50% and 100%. Engine performance have been investigated and compared with the straight diesel fuel in a diesel engine. Aim of this study was to investigate effect of parameter like blend, compression ratio, injection pressure, and load on the performance of diesel engine using Karanja biodiesel. Input parameter that is injection pressure, blend ratio, load and CR are taken as variable for optimizing result for BSFC. **Experimental results show that the various parameter are optimize using the Taguchi method. The Taguchi method used for**

**decreasing number of experiments and contribution of each noise factor calculated.**

14. **P.S. Kishore, V. Dhana Raju and Murahari Kolli** said that the current research focuses on using the Taguchi method to determine the best intake parameters for a diesel engine running on a TSME 20 biodiesel blend (80% diesel and 20% Tamarind seed methyl ester). Input parameters included injection pressure (IP), injection timing (IT), and exhaust gas recirculation (EGR), each with three levels. As performance parameters, brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), hydrocarbon (HC), nitrogen oxides (NOX), and smoke opacity (SO) were chosen. Taguchi L27 orthogonal array (OA) was used in this analysis. When dealing with responses influenced by multiple parameters, the Taguchi method is extremely effective; IT was discovered to have the greatest impact on BTE; NOX and smoke emissions were heavily influenced by EGR rate, which was followed by IT and IP. The tamarind seed methyl ester is an appealing choice for large-scale application in diesel engines in a country like India because it is widely available at a low cost. The novel use of Tamarind seed methyl ester (TSME 20) has a number of advantages, including improved diesel engine characteristics, significantly lower emission levels, cost-effectiveness, environmental friendliness, and long-term sustainability. **For the assessment of output S/N ratio, an experimental approach was used to optimise the intake parameters of a diesel engine. For BTE optimization, larger is better quality characteristics are used, while smaller is better quality characteristics are used for BSFC, HC, NOX, and smoke opacity.**

15. **S. Perumal and J. Udaya Prakash** told that the centered on grey relational review, this paper presents an effective method for optimising the tribological properties of hybrid aluminium matrix composites (356-B4Cp-MoS<sub>2</sub>) fabricated by stir casting technique, with multiple performance characteristics. B4C was held constant at 6% for all three composites (356-6 percent B4C, 356-6 percent B4C-2 percent MoS<sub>2</sub>,

and 356-6 percent B4C-4 percent MoS<sub>2</sub>) in this analysis, while MoS<sub>2</sub> was varied from 0% to 4% with a 2 wt% increment. Dry sliding wear experiments were carried out with a typical pin on disc test setup and a meticulously designed experimental schedule based on Taguchi's orthogonal arrays. Multiple performance characteristics, such as wear rate, individual wear rate, and coefficient of friction, are taken into account when optimising input parameters such as sliding speed, sliding distance, load, and reinforcement percentages. **The optimal levels of input parameters were chosen from the grey relational grade's response table and response graph. The significance of the wear parameters was determined using ANOVA.**

16. **N.V. Mahesh Babu Talupula et al.** include that the Biodiesel (mono alkyl esters) is a cleaner-burning diesel fuel made from sustainable natural resources such as vegetable oils. The use of biodiesel in a conventional diesel engine results in a significant reduction of unburned hydrocarbons, carbon monoxide, and other hazardous substances to the environment. Biodiesel blends well with modern technologies and catalysts, reducing the soluble fraction of diesel particulate but not the solid carbon fraction, particulate traps, and exhaust gas recirculation, all of which contribute to longer engine life. Due to the constant depletion of fossil fuels, a need has arisen to manufacture biodiesel from a variety of feedstocks. Using the Taguchi robust design method, the performance parameters that affect the production process were analysed using a L9 orthogonal array. The optimum yield of biodiesel was 93.8 percent with a viscosity of 5.60 cSt, a methanol-to-oil molar ratio of 4:1, catalyst concentration of 1.5 wt%, reaction time of 90 minutes, and reaction temperature of 600C, according to the findings. These are the recommended levels of controllable process factors when better Yield, lesser viscosity are simultaneously obtained. **The ANOVA of grey relational grade for multi-performance characteristics reveals that the catalyst concentration is the most significant parameter. The multi parameter output such as Yield and viscosity at 400C were optimized using grey relational analysis.**

17. **Naushad Ahamad Ansari et al.** include that Diesel fuel emissions are a significant source of air pollution and one of the major contributors to global warming. The current study focuses on the effects of polanga biodiesel blend, fuel injection timing, and fuel injection pressure on widely used single cylinder 4-stroke direct injection diesel engine emissions (Unburned Hydrocarbons-UHC, NO<sub>x</sub>, and smoke) and thermal performance at full load. The effect of polanga blends on fuel injection timing and fuel injection pressure was used as input factors in the analysis to analyse engine performance parameters, and the blends of polanga biodiesel produce the least amount of exhaust emissions. The operating conditions of the engine with a 30% polanga biodiesel blend at 220 bar injection pressure are close to the operating conditions with gasoline, according to the thermal efficiency evaluation. The Taguchi method has been modified to produce a rich architecture matrix for parameter optimization. The engine's input parameters are tailored for BTE, UHC, NO<sub>x</sub>, and smoke multi-response characteristics. **To evaluate the output characteristics from the real value, multiple single-to-noise ratio (MSNR) is used. At a 30 percent polanga biodiesel blend with 15o bTDC fuel injection timing and 200 bar injection pressure, the optimum values of BTE, UHC, NO<sub>x</sub>, and smoke emissions were 32.59 percent, 20.3 ppm volume, 551 ppm volume, and 94.2 percent, respectively.**
18. **M. Jena et al.** told that the preparation of Fe<sub>3</sub>-doped zinc oxide (FZO) by solution combustion synthesis, the Taguchi design of experiment and Grey relational analysis (GRA) were used to optimise various experimental parameters such as mol percent of Fe<sub>3</sub> doping, fuel, wt percent of NH<sub>4</sub>Cl flux, and calcination temperature. The crystallite size increases as the calcination temperature rises, while the band gap decreases as the mol percent of Fe<sub>3</sub> rises, according to the powder X-ray diffraction pattern of FZO. Grey relational grading reported that a combination of 5% doping, D-glucose fuel, 10% flux, and a calcination temperature of 600 C would result in a lower band gap energy (2.87 eV) and smaller crystallite size (11.63 nm). Finally, using Grey theory

predictions, we were able to select a combination of 5% doping, oxalic acid as a fuel, 5%  $\text{NH}_4\text{Cl}$  flux, and a calcination temperature of 500 C to achieve the necessary band gap of 2.61 eV and crystallite size of 10.12 nm. **Photocatalytic degradation of methyl orange(MO) dye was achieved using FZO NPs. As compared to other photocatalytic degradation results, the MO dye removal rate efficiency is higher (82.30 percent) on the Grey theory prediction result.**

## **CHAPTER 3**

### **MOTO OF THE PROJECT**

The world is faced with all problems of oil market scarcity, rising oil prices, and the depletion of the supply of fossil fuel. Biodiesel is a vegetable fuel sold as a viable alternative to petrol. There has previously been a mixture of diesel and a single biodiesel. Now done only a few studies have been carried out with different biodiesel formulations. It blends well with diesel and provides plenty of experimental space. In this thesis, biodiesels made of Bergamot oil with diesel will be treated separately. Biodiesel has been studied to influence motor performance and emissions. The air-cooled and high-speed diesel engine was tested at different speeds with one single cylinder, directly injected. The load of the motor is 3000 rpm. The emission methods were used to study the gas effect on CO, CO<sub>2</sub>, HC and other gases NO<sub>x</sub> and smoke opacity. Blend brakes were estimated to have a higher thermal efficiency than diesel brake efficiency. In biodiesel blends, emissions of smoke, hydrocarbons and nitrogen oxide were higher than in ethnlol. On the other hand, the exhaust gas temperature is higher in biodiesel generators. The proportion of blended oils was less than diesel fuel. The air-cooled and high-speed diesel engine was tested at various speeds with one single cylinder, directly injected. The load of the motor is 3000 rpm. The emission methods were used to study the gas effect on CO, CO<sub>2</sub>, HC and other gases NO<sub>x</sub> and smoke opacity. Blend brakes were estimated to have a higher thermal efficiency than diesel brake efficiency. In biodiesel blends, the emissions of smoke, hydrocarbons and nitrogen oxide were higher than those of ethanol. In biodiesel generators, however, the exhaust gas temperature is higher. The proportion of blended oils was less than diesel fuel.

#### **3.1 WHY OIL IS ENVIRONMENTALLY DAMAGING**

It is one of the most damaging greenhouse gases because it is a fossil fuel and leads to polluting emissions, in particular carbon dioxide. The ozone

greenhouse layer that plays an important role in regulating global temperatures has modified human emissions from greenhouse emissions.

### **3.2 GLOBAL WARMING OUTCOMES**

Temperature rises, water shortages, increased fire hazards, drought, invasions of weeds and pests, extreme storm destruction and salt invasion to name a few, are the effects of global warming for wildlife. One of the most popular natural attractions in Australia, the Great Barrier Reef, is now threatened.

### **3.3 CONSIDERATIONS AND BENEFITS FOR BIODIESEL**

Biodiesel is a petroleum diesel substitute manufactured domestically and clean-burning, renewable. The use of biodiesel as a vehicle fuel improves energy safety, enhances air quality and the atmosphere and offers safety advantages.

### **3.4 SECURITY AND BALANCE OF ENERGY**

In 2019, 3 percent of its petroleum was imported by the United States and the transport sector accounts for about 30% of the total energy requirements of the US and 70% of US oil consumption. Biodiesel and other renewable fuels and state-of-the-art technologies continue to enhance national security and reduce the energy cost to enterprises and customers for transport.

Biodiesel is manufactured and used in conventional diesel engines in the United States, directly replacing or expanding traditional oil diesel supplies.

### **3.5 QUALITY OF AIR**

Motors produced in 2010 and later must comply with the same emissions requirements, whether they are used on biodiesel, diesel or any other fuel. This is possible with selective catalytic (SCR) technology in diesel engines that reduces emissions of nitrogen oxide (NOx) to almost null and null. Emissions from diesel fuel motors are equivalent to emissions from biodiesel mixtures.

The use of biological diesel decreases life cycle pollution, because the carbon dioxide emitted from the combustion of biodiesel is compensated for by the carbon dioxide emanating from the rising fuel.

Argonne National Laboratory's life cycle analyses revealed the use of B100 decreases emissions of carbon dioxide by 74 percent compared with petroleum diesel. Similar values have been identified by the California Air Resources Board (CARB) from different sources for its biodiesel life cycle analysis.

Biodiesel's air quality advantages are about proportional to the amount of biodiesel included in the blend. Find out more on the emission of biodiesel.

### **3.6 OPERATION OF ENGINE**

Biodiesel enhances the lubricity of fuel and increases the fuel amount of cetane. Diesel engines rely on the lubricity of the fuel to prevent premature wear of moving parts. One of the unintended side effects of the federal regulations has been to decrease the lubricity of petroleum diesel, which reduce fuel sulphur by only 15 ppm and lower the aromatic material. The specification for diesel fuel ASTM D975 has been amended to include a lubricity requirement (a maximum wear scar diameter on the high-frequency reciprocating rig [HFRR] test of 520 microns). Biodiesel can increase diesel fuel lubricity by as little as 1% at mixing speeds.

Check your OEM (OEM) guidelines for your car before using biodiesel to decide the best combination for your car (see OEM information of the National Biodiesel Board for those who are supporting the use of biodiesel blends).

### **3.7 SAFETY**

Pure unblended biodiesel causes much less harm to or released into the atmosphere than petroleum diesel. It is better than diesel oil because it is less fuel. Biodiesel has a flashpoint above 130°C, compared to petroleum diesel at approximately 52°C. The handling, storage, and transport of biodiesel is clean. Refer to the Biodiesel Management and Use Guide for additional guidance on the treatment, storage and transport of biodiesel.

## CHAPTER 4

### METHODOLOGY

We attempted to determine the optimal Bergomot biodiesel and diesel blend for engine efficiency and emission characteristics of a diesel engine in this study. The load, blend ratio, and compression ratio are the input parameters used here. Each parameter was divided into four levels once more. Here, two output responses are optimised, with brake thermal efficiency (BTE) falling under the performance category and NO<sub>x</sub> falling under the emission category. A well-designed and planned experiment will yield results with a much smaller number of runs. As a result, Taguchi's method was chosen to determine the effect of various noise factors on the output.

#### 4.1 TAGUCHI METHOD

It's a statistical technique invented by **Dr. Genichi Taguchi** that uses a well-defined design of experiments to minimise variance in a method. A special set of arrays known as **orthogonal arrays** is used in this approach to minimise the number of experiments. These arrays provide detailed information on the various factors that influence the performance response. The orthogonal array is chosen based on the number of levels in each control factor and the number of control factors involved. This approach represents the quality characteristics that deviate from the target output using a statistical estimate of results known as the SNR. SNR is categorised by Taguchi into three categories: larger is better, smaller is better, and nominal is better. If the output response must be minimised, smaller is better SNR is acceptable and is calculated using equation. If the output response must be maximised, larger is better SNR is appropriate and is calculated using equation.

The larger the SNR, the better the BTE in this report, and the smaller the SNR, the worse the BTE. When it comes to NO<sub>x</sub>, the higher the SNR, the better.

The Taguchi form, on the other hand, is a little different. Since this is a multi-response optimization problem, the Grey-Taguchi method was used to produce a single response from various performance parameters.

## 4.2 GREY RELATIONAL ANALYSIS

**Grey relational analysis** was found to be a capable tool for analysing multi-response optimization problems since the research deals with multi-objective optimization of two response parameters. It is used to determine the essential factors of a system as well as their relationships. The input and output series identify the main factors here. The experimental data was first standardised between 0 and 1. After that, the normalised experimental results were used to calculate the grey relational coefficients (GRC). The grey relational grade (GRG) is then measured using the GRC. Finally, the grey relational coefficients are used to calculate the average grey relational grade. The GRG analysed the various process responses. The multi-response optimization problem is converted into a single-response optimization problem using this approach. The GRG with the highest peak value was selected as the best process parameters. The original sequence was optimised after the response parameters were optimised using the “higher the better” criterion.

The correlation between the expected output responses and the real experimental results is represented by the **Grey Relational Coefficient**.

We obtain CO, CO<sub>2</sub>, O<sub>2</sub>, HC, and NOX emission values using an experimental method on a high-speed, four-stroke, vertical, and air-cooled engine. In addition, we obtain another parametric value that is used to measure performance characteristics such as brake thermal efficiency and real fuel consumption. The various factors and levels for constructing an L16 orthogonal array are shown in Table 2. The experimental structure of the L16 orthogonal array used in the study is shown.

**Table 4.1 Levels and Factors of Experimental Investigation**

| <b>Factors</b>             | <b>Level 1</b> | <b>Level 2</b> | <b>Level 3</b> | <b>Level 4</b> |
|----------------------------|----------------|----------------|----------------|----------------|
| E310 composition (ppm)-A   | 15             | 30             | 45             | 60             |
| Load (%) -B                | 1.1            | 2.2            | 3.3            | 4.4            |
| Injection Pressure(Bar) –C | 180            | 200            | 220            | 240            |
| Bergomot oil blend (%) –D  | 10             | 20             | 25             | 30             |

**Table 4.2 L16 Orthogonal Array**

| <b>EX No</b> | <b>E310(ppm)</b> | <b>BP(KW)</b> | <b>IP(Bar)</b> | <b>LG(%)</b> |
|--------------|------------------|---------------|----------------|--------------|
| 1            | 15               | 1.1           | 180            | 10           |
| 2            | 15               | 2.2           | 200            | 20           |
| 3            | 15               | 3.3           | 220            | 25           |
| 4            | 15               | 4.4           | 240            | 30           |
| 5            | 30               | 1.1           | 200            | 25           |
| 6            | 30               | 2.2           | 180            | 30           |
| 7            | 30               | 3.3           | 240            | 10           |
| 8            | 30               | 4.4           | 220            | 20           |
| 9            | 45               | 1.1           | 220            | 30           |
| 10           | 45               | 2.2           | 240            | 25           |
| 11           | 45               | 3.3           | 180            | 20           |
| 12           | 45               | 4.4           | 200            | 10           |
| 13           | 60               | 1.1           | 240            | 20           |
| 14           | 60               | 2.2           | 220            | 10           |
| 15           | 60               | 3.3           | 200            | 30           |
| 16           | 60               | 4.4           | 180            | 25           |

## CHAPTER 5

### EXPERIMENTAL SETUP

A single cylinder, constant speed, Direct injection engine was used to evaluate the engine performance and emission characteristics of bergamot bio diesel. The diesel runs under different load conditions at a constant speed of 1500 rpm with the different blend proportions. The diesel engine was directly attached with an eddy current dynamometer for varying the loads from no load (0%) to full load (100%). Based on the engine power, the engine load is varied from no load condition of 0%, 25%, 50%, 75% and full load conditions of 100%. The engine loads are varied manually with help of an eddy current dynamometer. Air flow rate was measured with an air drum fitted with a calibrated orifice and the fuel flow was measured using volumetric calibrated burette method. For fuel flow measurement, two fuel tanks were used; one is filled with pure diesel while transesterified bergamot biodiesel is filled in another fuel tank. An AVL smoke meter was attached for measuring the smoke opacity and exhaust gas temperatures. The test rig was installed with AVL indimicro software to obtain various readings and results during operation. A five gas analyzer was used to measure the emission characteristics such as HC, CO, CO<sub>2</sub>, O<sub>2</sub> and NOX values from the exhaust gas.

The performance and emission tests were conducted at the compression ratio of 17.5 and with rated power.

The test was carried out for different blend proportions of bergamot biofuel blended with the pure diesel fuel. The performance analysis of the engine at different rated power was evaluated in terms specific fuel consumption (SFC), Brake thermal efficiency (BTE) and emissions characteristics such as HC, CO, CO<sub>2</sub>, and NOX. FIG: shows the photographic view of the experimental setup used in this study.



***Figure 5.1 Photographic View of Experimental Setup***

**Table 5.1 Specifications of the Test Engine**

|                     |                                                |
|---------------------|------------------------------------------------|
| Engine type         | Single cylinder ,4 stroke ,water cooled engine |
|                     | Stroke 110mm, bore 87.5mm, 661cc               |
| Power               | 5.20kw @1500rpm                                |
| Compression         | 17.5                                           |
| Injection variation | 0-25 deg bTDC                                  |
| Dynamometer         | Eddy current, water cooled with loading unit   |
| Fuel tank           | 15 lt, Dual compartment with fuel metering     |

Engine soft is lab view based software package developed by Apex innovations Pvt. Ltd. For engine performance monitoring system. Engine soft can serve most of the engine testing application needs including monitoring, reporting, data entry, data logging. The software evaluates power, efficiencies, fuel consumption and heat release. It is configurable as per engine is run mode necessary signals are scanned, stored and presented in graph. While on line testing of the engine in RUN mode necessary signals are scanned, stored and presented in graph. Stored data file is accessed to view the data graphical and tabular formats. The results and graph can be printed. The data in excel format can be used for further analysis.

## **5.1 TEST RUN WITH COMPUTERIZED MULTI CYLINDER ENGINE SETUPS**

- Ensure that all the nut bolts of engine, dynamometer, propeller shaft, base frame are properly tightened.
- Ensure that sufficient lubrication oil is present in the engine sump tank. This can be checked by marking on the level stick.
- Ensure sufficient fuel in fuel tank. Remove air in fuel line, if any.

- Switch on electric supply and ensure that PPU (piezo powering unit AX-409), DLU (dynamometer loading unit AX-155), load indicator and voltmeter are switched on.
- Start computer and open “ICENGINEISOFT” (double click “ICENGINEISOFT” icon on the desktop ) select :File| configure | product
- In “configure the product “ windows select “load default”
- Under “select file” choose your setup from drop down menu
- Under “set parameters” the under ok. Study parameters engine, sensors, combustion and performance tabs. Click on
- Changing the parameters:
- If any parameter changed click “New /change the parameter under respective tabs .After all change click “Save & Apply “. Click “ok” to save changes.
- Click “OK” again to reconfigure changes C
- Reconfigure the graphs
- Select file | configure | Graph. Under “Configure the Graphs” window. “Select a configuration “from the drop down menu.
- “CLOSE & SET” click “SAVE” study the preset configuration of X axis, Y axis, graph ranges, for the selected graphs. Click configure the necessary parameter ranges as required.
- Then “Close and SET”
- Note three vertical tabs viz. combustion, performance, report. Under vertical combustion tab horizontally following tabs are available: combustion, cylinder pr. , pv , Log PV and RPR etc. Similarly under other vertical tabs we get more horizontal tabs. Start water pump. Adjust the flow rate of “Rotameter (Engine)” to 900-1000 LPH and “Rotameter (calorimeter)” to 200-250 LPH by manipulating respective globe values

provided at the rotometer inlet. Ensure that water is flowing through dynamometer at a pressure of @ 0.5 to 1 kg/cm<sup>2</sup>. (For Hydraulic dynamometer at a pressure of @ 1.5 to 2 kg/cm<sup>2</sup>)

- Keep the DLU knob at minimum position. Change the fuel cock position from “Measuring”.
- “Tank”. start the engine by starter keys switch and allow it to run at idling condition for 4-5 minutes.

## **5.2 ONLINE DATA ACQUISITION**

“Mode” “Measurement” click toggle switch to start/stop the device communication. Green color indicates ON condition. Click toggle switch to start/stop data acquisition. Green color indicates ON condition.

Ensure that speed, temperature and manometer reading are correctly displayed on the pc. These readings should tally with those displayed on the engine panel.

Increase the load on the engine by rotating knob on the DLU and confirm the load reading on the indicator and computer are same.

Gradually increase throttle to full open condition and load the engine simultaneously maintaining engine speed at @2000-2500 RPM. Flow, calorimeter jacket cooling water flowing LPH click “OK” after.

Wait for steady state for @ 3minutes and ensure that RPM & load is constant during this period. Change the fuel cock position from “tank” to “measuring”. Click “log on” on. The fuel metering is ON for next 60 seconds. During first 30 seconds enter engine water recording fuel reading. Enter the file name under which the records to be stored. The first reading data is now saved. Change the fuel cock position from “Measuring” to “Tank”.

Gradually decrease the load to the increase speed in steps of @500 RPM up to @ 4000 rpm maximum and repeat the data logging for each observation.

After finishing all the readings simultaneously decrease the load on the engine by DLU. Gradually decrease throttle to full down condition.

“Measureme” ”Mode” click toggle switch to stop data acquisition on PC (Green color indicates ON condition). Click toggle switch to stop the device communication

Click: File | Data | close. Stop the engine by pressing engine stop starters keys. Allow the water to circulate for about 5 minutes for engine cooling and then stop the pump.

Click: File | Data | open .on PC, select the File under which the readings are stored and click “OK”. To view next readings click “Next Data”. The results are displayed on all the three screens.

Click tab for performance Enter File name “Report File” .Select Report Printing: Report generating Report, combustion Report.

The Report Requirement viz. Result data, Observation Data .Graph only OR Graph and Table. (Note if “Graph and Table” options selected under Combustion report, the size of the output file for printing becomes too big. However it can be viewed in Excel) Click: File | Data | Close. After printing & checking .Click “Exit” and then shut Down the computer.

### **5.3 SMOKEMETER**

To take the readings from Smokemeter to ADCS Software kindly follow these steps.

- Kindly fill the details(Engine No. Model, Engine Type, Engine Speed) in respective text boxes given on the form if you didn't check “Vehicle details” check box in Master data entry form all the textboxes related to(Engine No. Model, Engine Type, Engine Speed) becomes disabled.
- Click on “Connect button” to connect the PC with equipment and wait for 5-10 seconds. If the readings are not coming it show the message in red

colour” Unable to Communicate with Equipment” kindly check the following:

- Be sure that Smokemeter model name display on screen is same as your smokemeter model if not kindly change the model in “Master Data Entry Form”.
- Check the COM port settings with PC and the software in “Master Data Entry” Form.
- RS232 Cable for smokemeter is working properly and connected with equipment.
- Readings are coming with equipment and display on remote of smokemeter.
- According to “Time interval settings in selection box, readings are automatically saves in database”.
- After taking the readings click on “Disconnect button” it disconnect the communication with equipment and show the message “Disconnected”.
- Report: Click on report button to take the report of the test.
- Print: Click on print button to take the printout of screen as bitmap image.
- Export to MS Excel sheet: To export data in excel sheet click on “EXPORT TO EXCEL” button. When pressing export button a excel file is generated at path “C:\ AVLFolder\”. The file name of excel file is same as Test Date and VIN no(Tuesday, January 06, 2009\_26).
- Close button: click on close button to exit from current active window or screen, it takes time to close, so wait for 10-15 seconds for form window to close.



**Figure 5.2 Smokemeter**



**Figure 5.3 Linearity Test**

#### 5.4 GAS ANALYZER

To take the readings from Gas analyzer to ADCS Software kindly follow these steps.

- Kindly fill the details (Engine No. Model, Engine Type, Engine Speed) in respective text boxes given on the form.

- Click on “Connect button” to connect the PC with equipment and wait for 2-3 minutes. If the readings are not coming it show the message in red colour “CO HC power not communicating.” Kindly check the following:
- Be sure that gas analyzer setting in “MAHA Euro” mode.
- Check the COM port settings with PC and the software.
- RS232 Cable is working properly and connected with equipment.
- Readings are coming with equipment and display on panel.
- After 6 seconds readings are automatically save in database and status bar strip moving according to readings save in database.
- After taking the readings click on “Disconnect button” it disconnect the communication with equipment and show the message “Data Saved in Database”.
- Report: Click on report button to take the report of the test.
- Print: Click on print button to take the printout of screen as bitmap image.
- Export to MS Excel sheet: To export data in excel sheet click on “EXPORT TO EXCEL” button. When pressing export button a excel file is generated in a path “C:\ AVLFolder\”.The file name of excel file is same as Test Date and VIN no (Tuesday, January 06,2009\_23).
- Close button: click on close button to exit from current active window or screen.



**Figure 5.4 Five Gas Analyzer Reading**



**Figure 5.5 Five Gas Analyzer**

## **CHAPTER 6**

### **RESULT AND DISCUSSION**

#### **6.1 PREDICTIONAL VALUES USING EXPERIMENTAL DATA**

The experimental results for engine performance and emission characteristics are given in the table 5. In case of engine performance, the maximum brake thermal efficiency is observed at 50% load, Blend B 30, 180bar injection pressure and 30ppm E310 combination sample. The minimum brake specific fuel consumption is observed at 100% load, Blend B 30, the E310 composition of 30ppm and the injection pressure of 240bar.

In case of emission study, the minimum amount of CO was emitted at 50% load, Blend B30, E310 15ppm with 240bar injection pressure. The minimum amount of HC was emitted at E310 45ppm, 75% load, injection pressure at 180 bar and Blend B20. The minimum CO<sub>2</sub> was emitted during investigation in E310 60ppm, 50% load, injection pressure at 220 bar and Blend B 10. The maximum amount of O<sub>2</sub> is emitted at the combination at E310 15ppm, 100% load, injection pressure at 240 bar and Blend B30. The minimum amount of NO<sub>x</sub> was emitted at 45ppm of E310, 100% load, injection pressure at 200 bar and Blend B10. During the investigation, the minimum CO<sub>2</sub> was released in E310 60ppm, 50% load, injection pressure of 220 bar, and Blend B 10. At E310 15ppm, 100 percent load, injection pressure of 240 bar, and Blend B30, the maximum amount of O<sub>2</sub> is released. At 45ppm E310, 100 percent load, 200 bar injection pressure, and Blend B10, the least amount of NO<sub>x</sub> was emitted.

**Table 6.1 Taguchi Table of Performance and Experimental emission value**

| <b>EX No</b> | <b>BTE (%)</b> | <b>SFC (kg/Kw h)</b> | <b>HC (ppm)</b> | <b>CO (%)</b> | <b>CO<sub>2</sub> (%)</b> | <b>O<sub>2</sub>%</b> | <b>NO<sub>x</sub> (ppm)</b> |
|--------------|----------------|----------------------|-----------------|---------------|---------------------------|-----------------------|-----------------------------|
| 1            | 17.4           | 0.354                | 8               | 0.046         | 5.3                       | 16.9                  | 165                         |
| 2            | 24             | 0.34                 | 15              | 0.052         | 5.1                       | 16.06                 | 520                         |
| 3            | 25.08          | 0.337                | 24              | 0.063         | 4.9                       | 16.8                  | 724                         |
| 4            | 33.2           | 0.23                 | 29              | 0.023         | 4.1                       | 12.16                 | 914                         |
| 5            | 15.8           | 0.304                | 7               | 0.074         | 4.7                       | 13.55                 | 175                         |
| 6            | 25.8           | 0.265                | 18              | 0.068         | 3.8                       | 12.43                 | 501                         |
| 7            | 27.9           | 0.505                | 22              | 0.047         | 2.6                       | 12.74                 | 754                         |
| 8            | 33.95          | 0.38                 | 31              | 0.055         | 1.9                       | 14.88                 | 923                         |
| 9            | 18.4           | 0.27                 | 10              | 0.061         | 2.4                       | 13.53                 | 140                         |
| 10           | 26.4           | 0.308                | 20              | 0.078         | 1.6                       | 12.77                 | 542                         |
| 11           | 23.5           | 0.4                  | 21              | 0.033         | 2                         | 11.04                 | 761                         |
| 12           | 31.4           | 0.606                | 31              | 0.047         | 1.1                       | 16.48                 | 936                         |
| 13           | 17.89          | 0.306                | 11              | 0.043         | 1.6                       | 15.36                 | 135                         |
| 14           | 27.5           | 0.61                 | 19              | 0.045         | 1.2                       | 16.72                 | 561                         |
| 15           | 31.91          | 0.283                | 28              | 0.040         | 4.2                       | 12.23                 | 729                         |
| 16           | 30.89          | 0.343                | 32              | 0.0365        | 2.70                      | 14.32                 | 951                         |

From 16 experimental investigations, the above predictions assist in evaluating the best feasible solution for an individual engine's efficiency and emission values. However, we must transform this multi-response data into a single response data set. To transform multi-response data into single-response data, grey relational analysis techniques were used. To use Grey relational analysis to find the best method parameters, the following steps were taken into consideration.

## 6.2 CALCULATION OF S/N RATIO

The maximum signal-to-noise (S/N) ratio values are used to represent the output characteristic, whereas the lower S/N Ratio values are used to represent the emission characteristic in this analysis. Following formulae, the S/N ratios with a lower-the-better and larger-the-better characteristics were determined, and the results are shown in Table 6.1.

$$(i) \quad \text{Larger the better} = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^n \frac{1}{y_{ij}^2} \right) \quad (6.1)$$

$$(ii) \quad \text{Smaller the better} = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^n y_{ij}^2 \right) \quad (6.2)$$

Where n=number of replications,  $y_{ij}$  = observed response value, where  $i = 1, 2, \dots, n$ ;  $j = 1, 2, \dots, k$ .

**For maximisation problems, the larger the better, and for minimization problems, the smaller the better.**

**Table 6.2 S/N Ratio Values for BTE, SFC, CO, CO<sub>2</sub>, HC, O<sub>2</sub> and NO<sub>x</sub>**

| EX No | BTE (%) | SFC (kg/Kw h) | HC (ppm) | CO (%)  | CO <sub>2</sub> (%) | O <sub>2</sub> % | NO <sub>x</sub> (ppm) |
|-------|---------|---------------|----------|---------|---------------------|------------------|-----------------------|
| 1     | 28.5627 | 8.3134        | -30.1030 | 24.4370 | -17.2665            | -24.5577         | -60.0174              |
| 2     | 27.2346 | 8.6360        | -32.6694 | 24.1522 | -17.0252            | -24.2757         | -79.3697              |
| 3     | 28.0898 | 9.4474        | -28.6273 | 22.7335 | -16.7770            | -24.5577         | -59.5086              |
| 4     | 30.4749 | 12.5971       | -31.8213 | 30.4576 | -15.7066            | -21.6269         | -61.8684              |
| 5     | 28.6273 | 9.7891        | -30.8814 | 22.6154 | -16.5215            | -22.7027         | -60.9065              |
| 6     | 29.8272 | 11.0104       | -31.3640 | 22.1581 | -15.2686            | -21.7485         | -58.7904              |
| 7     | 29.2180 | 4.8066        | -29.5424 | 24.8825 | -13.2552            | -22.0761         | -57.5012              |
| 8     | 27.2157 | 9.4043        | -30.1030 | 26.9357 | -11.8213            | -23.5102         | -58.2869              |
| 9     | 29.1030 | 11.3727       | -30.6296 | 24.2934 | -12.8691            | -22.5615         | -57.8419              |
| 10    | 29.0265 | 10.0891       | -32.0412 | 22.8172 | -11.1261            | -22.0555         | -56.9020              |
| 11    | 26.8682 | 7.7443        | -24.6092 | 29.6297 | -12.0412            | -23.5450         | -57.4431              |
| 12    | 29.3669 | 4.0685        | -26.4444 | 27.9588 | -8.6273             | -24.5474         | -52.6289              |
| 13    | 27.4840 | 8.3815        | -30.3703 | 27.5350 | -11.1261            | -23.7842         | -57.1707              |
| 14    | 28.5627 | 4.4370        | -30.1030 | 26.5580 | -8.2995             | -24.5165         | -52.6694              |
| 15    | 29.8020 | 10.6626       | -28.9432 | 27.3306 | -15.8478            | -21.6772         | -62.1170              |
| 16    | 29.2510 | 10.0891       | -26.8485 | 28.5194 | -13.4420            | -23.0580         | -60.2145              |

### 6.3 CALCULATION OF NORMALIZATION VALUES

We proceed to the normalisation step after calculating the S/N Ratio for various output and emission characteristics values. Normalization is a transformation that is applied to a single data input to uniformly distribute the data and scale it into a usable range of zero to one for further analysis [NO]. The grey relational generation is the name given to this normalisation method. The categories for normalising the original sequence are determined based on consistency characteristics. By solving equations, the normalisation values for engine output variables are determined, and the results are tabulated in Table 6.3.

If the initial sequence data is 'larger-the-better,' it is pre-processed as 'larger-the-better,' and the formula is used to quantify it.

$$x_i^*(k) = \frac{x_i^{(0)}(k) - \min x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad (6.3)$$

If the initial sequence data is 'smaller-the-better,' the data is pre-processed as 'smaller-the-better,' and the formula is used to calculate it.

$$x_i^*(k) = \frac{\max x_i^{(0)}(k) - x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad (6.4)$$

**Table 6.3 Normalization Table**

| EX No | BTE (%) | SFC (kg/Kwh) | HC (ppm) | CO (%) | CO <sub>2</sub> (%) | O <sub>2</sub> (%) | No <sub>x</sub> (ppm) |
|-------|---------|--------------|----------|--------|---------------------|--------------------|-----------------------|
| 1     | 0.4698  | 0.9770       | 0.6816   | 0.7254 | 1.0000              | 1.0000             | 0.7787                |
| 2     | 0.1016  | 0.4645       | 1.0000   | 0.7597 | 0.9731              | 0.9038             | 0.7104                |
| 3     | 0.3387  | 0.3693       | 0.4985   | 0.9307 | 0.9454              | 1.0000             | 0.7251                |
| 4     | 1.0000  | 0.0000       | 0.8948   | 0.0000 | 0.8260              | 0.0000             | 0.9738                |
| 5     | 0.4877  | 0.3292       | 0.7782   | 0.9449 | 0.9169              | 0.3670             | 0.8724                |
| 6     | 0.8204  | 0.1860       | 0.8381   | 1.0000 | 0.7772              | 0.0415             | 0.6494                |
| 7     | 0.6515  | 0.9135       | 0.6121   | 0.6717 | 0.5527              | 0.1532             | 0.5135                |
| 8     | 0.0963  | 0.4916       | 0.6816   | 0.4243 | 0.3928              | 0.6426             | 0.5963                |
| 9     | 0.6196  | 0.1436       | 0.7469   | 0.7427 | 0.5096              | 0.3189             | 0.5494                |
| 10    | 0.5984  | 0.2941       | 0.9221   | 0.9206 | 0.3152              | 0.1462             | 0.4504                |
| 11    | 0.0000  | 0.5690       | 0.0000   | 0.0997 | 0.4173              | 0.6544             | 0.5074                |
| 12    | 0.6928  | 1.0000       | 0.2277   | 0.3011 | 0.0366              | 0.9965             | 0.0000                |
| 13    | 0.1707  | 0.4943       | 0.7148   | 0.3521 | 0.3152              | 0.7361             | 0.4787                |
| 14    | 0.4698  | 0.9568       | 0.6816   | 0.4699 | 0.0000              | 0.9859             | 0.0043                |
| 15    | 0.8134  | 0.2268       | 0.5377   | 0.3768 | 0.8418              | 0.0172             | 1.0000                |
| 16    | 0.6606  | 0.2941       | 0.2778   | 0.2335 | 0.5735              | 0.4883             | 0.7995                |

The GRA Grade values are tabulated, and the overall grey relational grade is determined by averaging the grey relational coefficient corresponding to each selected process answer.

#### 6.4 COMPUTING GRA COEFFICIENT AND GRA GRADE

A grey relational coefficient is calculated to express the relationship between the actual normalised experimental results and all values of the distinguishing coefficient were set to 0.5(), and the values were calculated by solving equation.

$$\gamma = \frac{\Delta_{\min} + \varepsilon \Delta_{\max}}{\Delta_{oi}(k) + \varepsilon \Delta_{\max}} \quad (6.5)$$

Where,  $\Delta_{oi}(k) = |x_0^*(k) - x_i^*(k)|$ , is the absolute value of the difference between  $x_0^*(k)$  and  $x_i^*(k)$ .

$$\Delta_{\min} = \min_{j \in i} \min_k |x_0^*(k) - x_j^*(k)|, \text{ smallest value of } x_i(k)$$

$$\Delta_{\max} = \max_{j \in i} \max_k |x_0^*(k) - x_j^*(k)|, \text{ largest value of } x_i(k)$$

$\varepsilon$  ( $0 \leq \varepsilon \leq 1$ ) is the distinguishing coefficient and the value is taken as 0.5

We must produce the GRA Grade after calculating the GRA coefficient. The sum of the grey relational coefficients is used to measure the grey relational grade. The higher the grey relational grade, the closer the parameter combination is to the optimal setting, as shown in table 6.6 below. The Grey relational grade is calculated using the following formula:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \xi_i(k) \quad (6.6)$$

Where,  $\gamma$  is the grey relational grade and  $k$  is the number of performance characteristics

**Table 6.4 GRA Coefficient, GRA Grade with Rank**

| <b>EX No</b> | <b>BTE (%)</b> | <b>SFC (kg/Kwh)</b> | <b>HC (ppm)</b> | <b>CO (%)</b> | <b>CO<sub>2</sub> (%)</b> | <b>O<sub>2</sub> (%)</b> | <b>No<sub>x</sub> (ppm)</b> | <b>GRA Grade</b> | <b>Rank</b> |
|--------------|----------------|---------------------|-----------------|---------------|---------------------------|--------------------------|-----------------------------|------------------|-------------|
| 1            | 0.3575         | 0.4828              | 1.0000          | 0.6754        | 0.9489                    | 0.8386                   | 0.6333                      | 0.7052           | 2           |
| 2            | 0.4854         | 0.9560              | 0.6110          | 0.6455        | 1.0000                    | 1.0000                   | 0.6932                      | 0.7701           | 1           |
| 3            | 0.4306         | 0.4422              | 0.4993          | 0.8782        | 0.9016                    | 1.0000                   | 0.6452                      | 0.6853           | 3           |
| 4            | 1.0000         | 0.3333              | 0.8262          | 0.3333        | 0.7419                    | 0.3333                   | 0.9502                      | 0.6455           | 5           |
| 5            | 0.4939         | 0.4271              | 0.6927          | 0.9007        | 0.8575                    | 0.4413                   | 0.7967                      | 0.6586           | 4           |
| 6            | 0.7358         | 0.3805              | 0.7554          | 1.0000        | 0.6917                    | 0.3428                   | 0.5878                      | 0.6420           | 6           |
| 7            | 0.5893         | 0.8524              | 0.5631          | 0.6037        | 0.5278                    | 0.3713                   | 0.5069                      | 0.5735           | 10          |
| 8            | 0.3562         | 0.4958              | 0.6110          | 0.4648        | 0.4516                    | 0.5832                   | 0.5533                      | 0.5023           | 14          |
| 9            | 0.5679         | 0.3686              | 0.6640          | 0.6603        | 0.5048                    | 0.4233                   | 0.5260                      | 0.5307           | 12          |
| 10           | 0.5546         | 0.4146              | 0.8652          | 0.8629        | 0.4220                    | 0.3693                   | 0.4764                      | 0.5664           | 11          |
| 11           | 0.3333         | 0.5371              | 0.3333          | 0.3571        | 0.4618                    | 0.5913                   | 0.5037                      | 0.4454           | 16          |
| 12           | 0.6194         | 1.0000              | 0.3930          | 0.4170        | 0.3417                    | 0.9930                   | 0.3333                      | 0.5854           | 9           |
| 13           | 0.3761         | 0.4972              | 0.6368          | 0.4356        | 0.4220                    | 0.6545                   | 0.4896                      | 0.5017           | 15          |
| 14           | 0.4854         | 0.9205              | 0.6110          | 0.4854        | 0.3333                    | 0.9726                   | 0.3343                      | 0.5918           | 8           |
| 15           | 0.7282         | 0.3927              | 0.5196          | 0.4451        | 0.7596                    | 0.3372                   | 1.0000                      | 0.5975           | 7           |
| 16           | 0.5957         | 0.4146              | 0.4091          | 0.3948        | 0.5397                    | 0.4942                   | 0.7138                      | 0.5088           | 13          |

## 6.5 ANALYSIS OF VARIANCE (ANOVA)

The number of squared deviations from the total mean of the grey relational grade can be used to calculate analysis of variance (ANOVA), a statistical tool for analysing experimental results and making necessary decisions. The percentage contribution of regulated variables is shown in the ANOVA performance (engine parameters). The importance of process parameter adjustments on efficiency and emission characteristics was assessed using the percentage contribution corresponding to the engine process parameters in the total sum of the squared deviations. Furthermore, the F test was used to assess which engine

process parameters had a major impact on efficiency and emission characteristics. The F test was also used to see where engine process parameters have a major impact on performance and emission characteristics. When the F value is high, changes in the engine process parameter typically have a major impact on the output characteristics.

**Table 6.5 Analysis of Variance (ANOVA) for Grey Relational Grade**

| Engine Parameter        | Degree of freedom | sum of square | Mean square | F- value | p-value | % Contribution |
|-------------------------|-------------------|---------------|-------------|----------|---------|----------------|
| E310 composition (%)    | 3                 | 0.06969       | 0.06969     | 0.02323  | 6.169   | 62             |
| Load (%)                | 3                 | 0.01209       | 0.01209     | 0.00403  | 1.07    | 11             |
| Injection Pressure(Bar) | 3                 | 0.010387      | 0.01039     | 0.00346  | 0.919   | 9              |
| Bergomot oil blend (%)  | 3                 | 0.01829       | 0.01829     | 0.0061   | 1.612   | 16             |
| Residual Error          | 3                 | 0.002508      | 0.00251     | 0.00084  |         | 2              |
| Total                   | <b>15</b>         | 0.112965      |             |          |         | 100            |

The parameter of Nano catalyst E310 composition is 62 percent, followed by Bergomot oil blend 16 percent, Load 11 percent, and Injection Pressure 3 percent, according to the ANOVA performance. Engine output is primarily influenced by E310 composition, with Bergomot oil blend being the second most important influencing factor.

## 6.6 CONFIRMATION TESTS

The additivity rule can be used to predict the optimal value of a response variable. The approximate S/N ratio corresponding to the optimum level of process parameters was first calculated using the equation below.

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^q (\bar{\gamma}_i - \gamma_m) \quad (6.7)$$

Using MINI TAB, these validation tests were used to predict and check the change in quality characteristics for lower emission values in relation to the initial engine process parameters. The experiment was conducted with the optimal combination of parameters for the confirmation test, which were found to be 28.1 percent in BTE, 0.372 Kw/Kg h in SFC, Hydro carbon 29ppm, Carbon monoxide 0.065 percent, Carbon-dioxide 7.1 percent, Nitrogen Oxide 950 ppm, and 17.3 percent in oxygen. Table 6.8 compares the expected GRA Grade values to the real GRA Grade values obtained through experimental investigation with the best engine parameters. The rise in grey relational grade by 0.0553, with the grey relational value 0.8254, from the initial design GRA Grade value 0.7701, confirmed the improvement in Engine outputs.

**Table 6.6 Result of the Confirmation Test**

| Engine parameters            | Initial design | Optimal Engine parameters |            |
|------------------------------|----------------|---------------------------|------------|
|                              |                | Prediction                | Experiment |
|                              | A1B2C2D2       | A1B2C2D1                  | A1B2C2D1   |
| Break Thermal Efficiency (%) | 24             |                           | 28.1       |
| SFC(Kg/Kwh)                  | 0.34           |                           | 0.372      |
| Hydro Carbon(ppm)            | 15             |                           | 29         |
| Carbon monoxide(%)           | 0.05           |                           | 0.065      |
| Carbon dioxide(%)            | 5.1            |                           | 7.1        |
| Nitrogen Oxide(ppm)          | 520            |                           | 650        |
| Oxygen(%)                    | 16.06          |                           | 17.3       |
| Grey Relational Grade        | 0.7701         | 0.7824                    | 0.8254     |

## **CHAPTER 7**

### **CONCLUSION**

Using the Taguchi method and grey relational analysis, we attempted to determine the effects of different input parameters such as engine load, blend, and different levels on the efficiency (BTE) and emission parameters (NO<sub>x</sub>) of a CI engine controlled with different blends of diesel and Bergomot biodiesel.

- The number of experiments was reduced to 16, and 16 different combinations of input parameters were tested.
- With the assistance of a grey relational grade and sufficient weighting variables, the grey relational analysis transforms multiple objective optimisations into single objective optimisation problems.
- The best factor setting is achieved using the Grey-Taguchi system.
- There were confirmed that E310 composition 15ppm, Load 2.2%, Injection pressure 200Bar, Blend 20%.
- The relative impact of control factors on output responses was investigated using ANOVA, and the relative contribution of load was found to be the largest, at 62 percent.

As a result, the optimal input parameters for diesel engine efficiency were discovered.

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