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Experimental Investigation of the Suitability of Orange Peel Oil as a Blend with Cotton Seed Oil as Alternate Fuel for Diesel Engines

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Abstract- As a renewable, sustainable and alternative fuel for compression ignition engines, biodiesel instead of diesel has been increasingly fueled to study its effects on engine performances and emissions in the recent 10 years. But these studies have been rarely reviewed to favor understanding and popularization for biodiesel so far. In this work, reports about biodiesel engine performances published by highly rated journals in scientific indexes, were cited preferentially since 2000 year. From these reports, the effect of biodiesel on engine power, economy, durability and the corresponding effect factors are surveyed and analyzed in detail. The use of biodiesel leads to the imperceptible power loss, the increase in fuel consumption and increase in break thermal efficiency in conventional diesel engines with no or fewer modification. And it favors to reduce carbon deposit and wear of the key engine parts. Therefore, the blends of biodiesel with small content in place of petroleum diesel can help in controlling air pollution and easing the pressure on scarce resources without significantly sacrificing engine power and economy. However, many further researches about optimization and modification on engine, low temperature performances of engine, new instrumentation and methodology for measurements, etc., should be performed when petroleum diesel is substituted completely by biodiesel.

Index Terms- Bio-fuel, Performance, Emissions, alternative fuel

I. Introduction

Diesel engine will be the major power source for automobiles in the twenty-first century. To reduce emissions and solve the energy crisis, designing diesel engines with low emission and less energy consumption has always be an objective for researchers across the globe. However, with the development of new technologies, today's diesel engines have better emission characteristics and the less energy consumption compared with its predecessor. But, there is still lot to do on diesel engines aimed to achieve our goal of clean and effective diesel engine. Accordingly, research on a clean burning fuel instead of conventional fuel is advisable, which could not only decrease exhaust gas to a great extent, but, also provide more options of energy sources. The use of alternative fuels for internal combustion engines has attracted a great deal of attention due to fossil fuel crisis and also GHG impact. Alternative fuels should be easily available, environment friendly, and techno-economically competitive. Successful alternative fuel should fulfill environmental and energy security needs without sacrificing engine operating performance. Renewable resources offer the opportunity to tap local resources and reduce dependency on fossil energy resources. Most biodiesel oils, particularly of the nonedible type can be used as fuel in diesel engines. One of the promising alternative fuels considered for diesel engine is biodiesel.

Biodiesel fuels are renewable, as the carbon released by the burning of biodiesel fuel is used when the oil crops undergo photosynthesis. Biodiesel also offers the advantage of being able to readily use in existing diesel engines without engine modifications. The alkyl monoester of fatty acids as bio-diesel which was obtained from renewable oil and fats materials by transesterification reaction is a good alternative. Biodiesel can be obtained from raw vegetable oil by transesterification with methanol or ethanol after chemical reactions. Vegetable oils present a very promising alternative to diesel oil since they are renewable and have similar properties as of diesel. Many researchers have studied the use of vegetable oils in diesel engines. This recommends the intensive studies on the use of alternative fuels especially renewable ones like vegetable oils and alcohols. Biodiesels such as Jatropha, Karanja, Sunflower and cottonseed are some of the popular biodiesels currently considered as substitute for diesel.

When biodiesel is used as a substitute for diesel, it is highly essential to understand the parameters that affect the combustion phenomenon which will in turn have direct impact on thermal efficiency and emission. In the present energy scenario lot of efforts is being focused on improving the thermal efficiency of IC engines with reduction in emissions. The problem of increasing demand for high brake power and the fast depletion of the fuels demand severe controls on power and a high level of fuel economy.

II. LITERATURE SURVEY

2.1 Diesel Engine

A **diesel engine** (a type of **compression-ignition engine**) is an internal combustion engine that uses the heat of compression to initiate ignition and burn the fuel that has been injected into the combustion chamber. This contrasts with spark-ignition engines such as a petrol engine (gasoline engine) or gas engine (using a gaseous fuel as opposed to gasoline), which use a spark plug to ignite an air-fuel mixture. The engine was developed by German inventor Rudolf Diesel in 1893.

The diesel engine has the highest thermal efficiency of any standard internal or external combustion engine due to its very high compression ratio. Low-speed diesel engines (as used in ships and other applications where overall engine weight is relatively unimportant) can have a thermal efficiency that exceeds 50%.

2.1.1 Brake specific fuel consumption (BSFC)

It is a measure of the fuel efficiency of a shaft reciprocating engine. It is the rate of fuel consumption divided by the power produced. It may also be thought of as power-specific fuel consumption, for this reason. BSFC allows the fuel efficiency of different reciprocating engines to be directly compared.

To calculate BSFC, use the formula

$$\mathbf{BSFC = x/p} \qquad (2.1)$$

Where:
x is the fuel consumption rate in grams per second (g/s)
P is the power produced in watts where P = T x N
N is the engine speed in revolutions per second
T is the engine torque in newton meters (N·m)

Commonly BSFC is expressed in units of grams per kilowatt-hour (g/kW·h). The conversion factor is as follows:
BSFC [g/kW·h] = BSFC [g/J]×(3.6×10^6)

An IC engine is used to produce mechanical power by combustion of fuel. Power is referred to as the rate at which work is done. Power is expressed as the product of force and linear velocity or product of torque and angular velocity. In order to measure power one needs to measure torque or force and speed. The force or torque is measured by Dynamometer and speed by Tachometer. The power developed by an engine and measured at the output shaft is called the brake power (bp) and is given by,

$$BP = \frac{2\pi NT}{60} \qquad (2.2)$$

Where:
T is the torque,
N is the rotational speed,

However while calculating the Mechanical efficiency another factor called Indicated power is considered. It is defined as the power developed by combustion of fuel in the combustion chamber (IP). It is always more than brake power. It is given by

$$IP = \frac{PmLANk}{60} \qquad (2.3)$$

Where:
P_m is the mean pressure,
A is the area of the piston
N is Rotational speed of the engine, rpm (It is N/2 for four stroke engine), and
k is the number of cylinders
L is length of stroke

Therefore the difference between ip and bp indicates the power loss in the mechanical components of engine (due to friction). So the mechanical efficiency is defined as ratio of brake power to the indicated power. Friction power is the difference between indicated power and brake power.

2.1.2 Thermal Efficiency and Heat Balance

Thermal efficiency of an engine is defined as the ratio of the output to that of the chemical energy Input in the form of fuel supply. It may be based on brake or indicated output. It is the true indication of the efficiency with which the chemical energy of fuel (input) is converted into mechanical work. Thermal efficiency also accounts for combustion efficiency, i.e., for the fact that whole of the chemical energy of the fuel is not converted into heat energy during combustion.

$$\textbf{Brake thermal efficiency} = \frac{b\,p}{m_f \times CV} \qquad (2.4)$$

Where,
CV = Calorific value of fuel, kJ/kg, and
m_f = Mass of fuel supplied, kg/sec.

The energy input to the engine goes out in various forms – a part is in the form of brake output, a part into exhaust, and the rest is taken by cooling water and the lubricating oil. The break-up of the total energy input into these different parts is called the **Heat Balance**. The main components in a heat balance are brake output, coolant losses, heat going to exhaust, radiation and other losses. Preparation of heat balance sheet gives us an idea about the amount of energy wasted in various parts and allows us to think of methods to reduce the losses so incurred.

2.1.3 Exhaust Smoke and Other Emissions

Smoke and other exhaust emissions such as oxides of nitrogen (NOx), unburned hydrocarbons (UBHC), etc. are nuisance for the public environment. With increasing emphasis on air pollution control all efforts are being made to keep them as minimum as it could be. Smoke is an indication of incomplete combustion. It limits the output of an engine if air pollution control is the consideration. Exhaust emissions have of late become a matter of grave concern and with the enforcement of legislation on air pollution in many countries; it has become necessary to view them as performance parameters.

2.2 Criteria for a Fuel to be Engine Fuel

In IC engine, the thermal energy is released by burning the fuel in the engine cylinder. The combustion of fuel in IC engine is quite fast but the time needed to get a proper air/fuel mixture depends mainly on the nature of fuel and the method of its introduction into the combustion chamber.

The fuel should therefore satisfy the following performance.
1. High energy density.
2. Good combustion characteristics.

3. High thermal stability.
4. Low deposit forming tendencies.
5. Compatibility with the engine hardware.
6. Good fire safety.
7. Low toxicity.
8. Less pollution.
9. Easy transferability and onboard vehicle storage.

The combustion process in the cylinder should take as little time as possible with the release of maximum heat energy during the period of operation. Longer operation results in the formation of deposits which in combination with other combustion products may cause excessive wear and corrosion of cylinder, piston and piston rings. The combustion product should not be toxic when exhausted to the atmosphere. These requirements can be satisfied using a number of liquid and gaseous fuels. The biodiesel from non edible sources like Jatropha, Pongamia, Mahua, Neem etc. meets the above engine performance requirement and therefore can offer perfect viable alternative to diesel oil in India.

2.3 Biodiesel Standard

Biodiesel has a number of standards for its quality. The European standard for biodiesel is EN 14214, which is translated into the respective national standards for each country that forms the CEN(European Committee for Standardization) area e.g., for the United Kingdom, BS EN 14214 and for Germany DIN EN 14214. It may be used outside the CEN area as well. The main difference that exists between EN 14214 standards of different countries is the national annex detailing climate related requirements of biodiesel in different CEN member countries.

Table 2.1: ASTM D-6751 / BIS standards for Biodiesel

sr.no.	***ASTM D-6751 / BIS standards for Biodiesel***	
11	Flash point (closed cup)	130°C min. (150°C average)
22	Water and sediment	0.050% by vol., max.
33	Kinematic viscosity at 40°C	1.9-6.0 mm2/s
44	Sulfated ash	0.020% by mass, max.
55	Sulfur	0.05% by mass, max.
66	Copper strip corrosion	No. 3 max
77	Cetane	47 min.
88	Carbon residue	0.050% by mass, max.
99	Acid number -- mg KOH/g	0.80 max.
110	Free glycerin	0.020 % mass
111	Total glycerine (free glycerine and unconverted glycerides combined)	0.240% by mass, max.
112	Phosphorus content	0.001 max. % mass
113	Distillation	90% @ 360°C

2.4 Features of Biodiesel

1. Biodiesel is a clean burning fuel
2. Biodiesel does not have any toxic emissions like mineral diesel
3. Biodiesel is made from any vegetable oil such as Soya, Rice bran, Canola, Palm, Coconut, mustard or peanut or from any animal fat like Lard or tallow.
4. Biodiesel is a complete substitute of Mineral diesel (HSD).
5. Biodiesel is made through a chemical process which converts oils and fats of natural origin into fatty acid methyl esters (FAME). Biodiesel IS NOT vegetable oil.
6. Biodiesel is intended to be used as a replacement for petroleum diesel fuel, or can be blended with petroleum diesel fuel in any proportion.
7. Biodiesel does not require modifications to a diesel engine to be used.
8. Biodiesel has reduced exhaust emissions compared to petroleum diesel fuel.
9. Biodiesel has lower toxicity compared to petroleum diesel fuel.
10. Biodiesel is safer to handle compared to petroleum diesel fuel.
11. Biodiesel quality is governed by ASTM D 6751 quality parameters.

2.5 Advantages and Disadvantages of Biodiesel

Compared to other alternative fuels, biodiesel fuel supports some unique features and qualities. Unlike any other alternative fuels, it has successfully passed all the health effects testing requirements, meeting the standards of the 1990 Clean Air Act Amendments

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2.5.1 Advantages of Biodiesel Fuel

- Biodiesel fuel is a renewable energy source unlike petroleum-based diesel.
- An excessive production of soybeans in the world makes it an economic way to utilize this surplus for manufacturing the Biodiesel fuel.
- One of the main biodiesel fuel advantages is that it is less polluting than petroleum diesel. The lack of sulfur in 100% biodiesel extends the life of catalytic converters.
- Another of the advantages of biodiesel fuel is that it can also be blended with other energy resources and oil.
- Biodiesel fuel can also be used in existing oil heating systems and diesel engines without making any alterations.
- It can also be distributed through existing diesel fuel pumps, which is another biodiesel fuel advantage over other alternative fuels.
- The lubricating property of the biodiesel may lengthen the lifetime of engines.

2.5.2 Disadvantages of Biodiesel Fuel

- At present, Biodiesel fuel is about one and a half times more expensive than petroleum diesel fuel.
- It requires energy to produce biodiesel fuel from crops; plus there is the energy of sowing, fertilizing and harvesting.
- Another biodiesel fuel disadvantage is that it can harm rubber hoses in some engines. As Biodiesel cleans the dirt from the engine, this dirt can then get collected in the fuel filter, thus clogging it. So, filters have to be changed after the first several hours of biodiesel use.
- Biodiesel fuel distribution infrastructure needs improvement, which is another of the biodiesel fuel disadvantages.

2.6 Characteristics of *Cottonseed* oil:

India is the fifth largest cotton producing country in the world today, the first-four being the U.S, china, Russia and Brazil. Our country produces about 8% of the world cotton. Cotton is a tropical plant. Cottonseed oil is a vegetable oil extracted from the seeds of the cotton. After being freed from the linters, the seeds are shelled and then crushed and pressed or treated with solvents to obtain the crude cotton seed oil. Cotton seed oil is one of the most widely available oils and it is relatively inexpensive.

2.7Comparision of Properties of Biodiesel & Diesel:

Table 2.2: Properties of Biodiesel and Diesel comparision

Ssr .no .	Test	Unit	Diesel	Blend		
			B00%	B20%	B30%	B40%
11	Colour		Golden	NA	NA	NA
22	Density	Kg/m^3	830	835	846	858
33	Viscosity	Cst	2.9	3.6	4.1	4.6
44	Cetane Number	_	51	51.3	51.4	52.4
55	CV	MJ/kg	42.5	41.3	41.18	40.1
66	Flash Pt.	℃	65	76	108	130
77	Fire pt.	℃	72	84	117	141

2.8 Pre-heating of Biodiesel

Different vegetable oils are considered as alternative fuels for diesel engines. The important advantages of vegetable oils as fuel are that they are renewable, can be produced locally, cheap and less pollutant for environment compared to diesel fuel. According to literature, use of vegetable oils as fuel in diesel engines causes several problems, namely poor fuel atomization and low volatility originated from their high viscosity, high molecular weight and density. After the use of vegetable oils for a long period of time, these problems may cause important engine failures. To improve fuel properties and decrease viscosity and density of oils, various methods such as heating the vegetable oils, mixing with diesel fuel, emulsion with alcohol and transesterification have been employed. Many experiments have clearly revealed that the widely applied and convenient method for reduction of viscosity and density of vegetable oils is transesterification.

III. SYSTEM DEVELOPMENT

3.1 Introduction

Direct injection diesel engines occupy an important place in the developing countries since they power agricultural pumps, small power tillers, light surface transport vehicles and other machineries. The problem of increasing demand for high brake power and the fast depletion of the fuels demand severe controls on power and a high level of fuel economy. Many innovative technologies are developed to tackle these problems. Modification is required in the existing engine designs. Some optimization approach has to be followed so that the efficiency of the engine is not comprised. As far as the IC engines are concerned the thermal efficiency and emission is the important parameters for which the other design and operating parameters has to be optimized.

DOE is a technique of defining and investing all possible combinations in an experiment involving multiple factors and to identify the best combination. In this, different factors and their levels are identified. Design of experiments is also useful to combine the factors at appropriate levels, each with the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results.

The methods of Design of Experiment are as follows:
1) Full Factorial method,
2) Taguchi method,
3) Response surface method and
4) Mixture method.

Among the available methods, Taguchi design is one of the most powerful DOE methods for analyzing the experiment. The salient features of this method are:

1) A simple, efficient and systematic method to optimize process to improve the performance and reduce cost.

2) Help arrive at the best parameters for the optimal conditions with the least number of experiments.

It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities.

DOE technique is used to identify the key factors that make the greatest contributions to the variation in response parameters of interest. It introduced the loss function concept which combines cost, target and variations into one metric. The signal-noise ratio is a Figure of merit and relates inversely to the loss function. It is defined as the ratio of the amount of energy for intended function to the amount of energy wasted. DOE recommends orthogonal array (OA) for lying out of the experiments which is significant part of this method. Instead of varying one factor at a time, all factors are varied simultaneously as per the design array and the response values are observed. It has the ability to evaluate several factors in a minimum number of tests. The results of the experiments are analyzed to achieve the following objectives.

- To establish the optimum conditions for the BTHE, BSFC, HC, NOx;

- To estimate the contributions of individual parameter to the response;
- To predict the response under optimum conditions;
- To develop mathematical model for thermal efficiency.
- To run the confirmation test for validation.

The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trend of influence of each parameter.

The steps involved in DOE method are:

- Identifying the response functions and control parameters to be evaluated;
- Determining the number of levels of the control parameters;
- Selecting the appropriate orthogonal array, assigning the parameters to the array and conducting the experiments;
- Analyzing the experimental results and selecting the optimum level of control parameters;
- Validating the optimal control parameters through a confirmation experiment.

To find optimum parameters, it is required to find out parameters which make maximum effect on the performance of diesel engine. Series of experiments were conducted for Specific Fuel Consumption and Brake Thermal Efficiency. Taguchi method is being applied to select the control factor levels (Blend Ratio, Injection Pressure and Engine Load and speed) to come up with optimal diesel engine control parameters.

There are two types of factors that affect functional characteristics that are control factors and noise factors. The factors which are easily control are control factors. Noise factors are those factors which are difficult or some time impossible or too expensive to control. The preferred parameter settings are then determined through the analysis of S/N ratio. There are three types of SN ratio, Smaller the best, Nominal the best and Larger the best, are selected depending on desire performance.

Once all SN ratios have been computed for each run of experiment, Taguchi advocates graphical approach to analyze the data. In the graphical approach, S/N ratios and average mean response are plotted for each factor against each of its levels. The optimum parameters are then examined through peak point in SN ratios. By using minitab16 software, 4 factors and 3 levels in Taguchi design of experiment method inserted and got following array perform experiment.

3.2 Determining Parameter Design Orthogonal Array

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter. If the difference between the minimum and maximum value of a parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then less value can be tested or the values tested can be closer together. Also, the cost of conducting experiments must be considered when determining the number of levels of a parameter to include in the experimental design. Typically, the number of levels for all parameters in the experimental design is chosen to be the same to aid in the selection of the proper orthogonal array.

Knowing the number of parameters and the number of levels, the proper orthogonal array can be selected. Using the array selector table shown below, the name of the appropriate array can be found by looking at the column and row corresponding to the number of parameters and number of levels. Once the name has been determined (the subscript represents the number of experiments that must be completed), the predefined array can be looked up. These arrays were created using an algorithm Taguchi developed, and allows for each variable and setting to be tested equally.

Table 3.1: Orthogonal Array Selection Table

Number of Levels	Number of Parameters (P)														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32						
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50				

Number of Levels	Number of Parameters (P)														
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L36	L36	L36	L36	L36	L36	L36								
4															
5															

3.3 Grey Relational Analysis.

Signal-to-noise ratio (S/N) is a measure used in science and engineering for comparing the level of a desired signal to the level of background noise. Since the present study aimed at optimizing eight response parameters, it might so happen that the higher S/N ratio for one performance characteristic may exhibit a lower S/N ratio for another characteristic. Therefore, the overall evaluation of the S/N ratio was required for the optimization of multiple performance characteristics. Grey relational analysis was found to be an efficient tool for analyzing this kind of problem. It was used to determine the key factors of the system and their correlations. The key factors were identified by the input and output sequences.

The experimental results were first normalized in the range between zero and one. Afterwards, the grey relational coefficients were obtained from the normalized experimental data to express the relationship between the desired and actual experimental data. Lastly, the overall grey relational grade was obtained by averaging the grey relational coefficients corresponding to each selected process response. The evaluation of the multiple process response was based on the grey relational grade. This method was employed to convert a multiple response process optimization problem into a single response problem with the objective function of overall grey relational grade. The corresponding level of parametric combination with the highest grey relational grade was considered as the optimum process parameter.

Therefore, when the target value of the original sequence was "the higher-the-better" the original sequence was normalized as follows:

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}. \quad (3.1)$$

When the purpose was "the lower-the-better" the original sequence was normalized as follows:

y_i (k) is the original reference sequence, x_i (k) is the sequence for comparison, $i = 1, 2, \ldots, m$,

$k = 1, 2, 3, \ldots, n$, with m, n being total no of experiments and responses. $\min y_i(k)$ is the smallest value of $y_i(k)$ and max $y_i(k)$ is the highest value of (k). Here, (k) was the value after the grey relational generation. An ideal sequence was x_0 (k).The grey relational grade revealed the relational degree between the experimental run sequences $[x_0(k)$ and $x_i(k)$, $i = 1, 2 \ldots]$.
The grey relational coefficient $\xi_i(k)$ could be calculated as

$$\xi_i(k) = \frac{\Delta_{\min} + \psi\Delta_{\max}}{\Delta_{oi}(k) + \psi\Delta_{\max}}, \quad (3.2)$$

Where,

$$\Delta_{0i} = \|x_0(k) - x_i(k)\|$$

was the difference of the absolute value between $x_0(k)$ and $x_i(k)$. Δmin, Δmax were the minimum and maximum values of the absolute differences ($\Delta 0i$) of all comparing sequences. The purpose of distinguishing coefficient ψ $(0 \leq \psi \leq 1)$ was to weaken the effect of Δmax when it became too large. After averaging the grey relational coefficients, the grey relational grade γo is to be calculated. The higher value of grey relational grade was considered to be the stronger relational degree between the ideal sequence $x_0(k)$ and the given sequence $x_i(k)$.The ideal sequence $x_0(k)$ was supposed to be the best process response in the experimental layout. Thus the higher relational grade implied that the corresponding parameter combination was closer to the optimal.

3.4 Grey Relational Grade Generation.

Accordingly, while converting multiple grey relation grades, the value of weighting factor in engine performance was taken higher than that of emission characteristics. When appropriate, weighting factors β was used with the sequence values; the general form of grey relational grades became

$$\gamma_o = \sum_{k=1}^{n} \xi_i(k)\beta\gamma_i \ldots, \quad \sum \beta = 1. \quad (3.3)$$

The different sequence value of weighting factor (β) could be specified from experience, or appropriate weights could be computed by processes such as singular value decomposition using preliminary grey relational grade values. One should note that the use of weighting factors would not be equivalent to changes in the sequence value units used or the choice made for sequence normalization.

The criteria for optimization of the response parameters was based on the smaller the better *S/N* ratio:

$$\frac{S}{N} = -10 \log \left[\frac{1}{r}\sum_{i=1}^{r} y_i^2\right] \quad (3.4)$$

Where, *yi* represents the measured value of the response variable *i*.

The *S/N* ratio with the higher – the-better characteristic can be expressed as:

$$\frac{S}{N} = -10 \log \left[\frac{1}{r}\sum_{i=1}^{r} {}^{1}/_{y_i^2}\right] \quad (3.5)$$

Where, *yi* represents the measured value of the response variable.

The negative sign is used to ensure that the largest value gives an optimum value for the response variable and therefore robust design.

3.5 ANOVA

The analysis of variance (ANOVA) is one of the most commonly used methods of analyzing experiments. It is a flexible and powerful tool of analysis. The mathematics involved requires diligence in calculation, yet the way ANOVA works is relatively simple.

In any experiment several factors are allowed to vary, a situation called experimental error exists. Experimental error is the random errors created in the experiment from the chance variations in uncontrollable factors such as quality of material, environmental conditions and operators involved. Taken together this experimental error creates a background "noise" in the data. ANOVA measures this background noise. The ANOVA measures the amount of signal each factor under study creates. The signal is the strength of the factor to create a real change in the response variable. If a factor is creating a signal that has more magnitude than the background noise, we say that this factor has the significant effect. Factor that cannot overcome the noise are said to be insignificant as we shall see even insignificant factors can be important in improvement.

ANOVA is an extremely useful technique concerning researchers in the field of engineering, technology, economy, biology, education, psychology, and sociology and business industries. In many industrial cases, we will have to compare three or more averages.

There may be variations between samples and within sample items. ANOVA consist of splitting the variances for analytical purpose. Hence it is the method of analyzing the variance to which response is subject in to its various components corresponding to various varieties of seeds or fertilizers or soils differ significantly so that the policy decision could be taken accordingly, concerning a particular variety in the context of agriculture research.

Thus through ANOVA technique one can, in general investigate any number of failure, which are hypothesized or said to influence the dependent variable. One may as well investigate the differences amongst various categories within each of these factors, which may have a large number of possible values. We are said to use one-way ANOVA and in case we investigate two factors at the same time, then we use two-way ANOVA. In two or more way ANOVA the interaction (i.e. interaction between two independent variable factors) if any, between two independent variables affecting a dependent variable can as well be studied for better decisions.

3.5.1Basic principles of ANOVA

The basic principle of ANOVA is to test for differences among of the population by examining the amount of variation within each of samples, relative to the amount of variation between the samples. In terms of variation within given population, it is assumed that the values of (X) differ from the mean of this population only because of random effects i.e. there are influences on (X) which are unexplainable, whereas in examining differences between populations we assume that the difference between the mean of j^{th} population and ground mean is attributable to what is called specific factor or what is technically described as treatment effect. Thus while using ANOVA we assume that each of the samples is drawn from normal population and that of these populations has the same variances. We also assume that all factors other than the one or more being tested are effectively controlled. Third in other words means that we assume the absence of many factors that might affect our conclusions concerning the factors to be studied.

3.5.2 Steps in ANOVA

Following steps are involved in carrying out ANOVA:

Carrying out the number of experiments as per design matrix selected maintaining the combination of factor level in each experiment as per experiment design.

1)Preparing ANOVA table as follows:

a)In first column put factor or interaction.

b)In second column put degree of freedom for each factor or interaction. This is obtained by number of factor levels minus one. For interaction, degree of freedom is obtained by product of degree of freedom of each interacting factor.

c)In third column put sum of squares calculated for each factor or interaction. This is traditional statistical calculation, which represents variability.

d)In fourth column put the value of mean sum of squares or variance by dividing the sum of squares by degree of freedom for each factor or interaction.

e)Sum of squares for all response values is calculated and is called total sum of squares. The difference between total sum of squares and the total of sum of squares of all the factors and interactions is called as residual or error or no effect sum of squares.

f)In fifth column ratio of variance (mean square) of each factor to the residual/error/no effect variance is calculated and put. This is called as variance ratio or 'F' ratio.

1)The F ratio will follow 'F' distribution with (i, j) degree of freedom. Find out the critical F values in ANOVA table with this critical value. If F value for a factor or interaction is exceeding critical F values then it can be concluded that the factor or interaction has a real effect on response variable. Larger the difference between F value and critical; F values from the table, larger is the effect of that particular factor or interaction on response variable.

2)If residual/error/no effect mean square (variance) is too high: it indicates improper factor selection and improper design of experiment.

Now computer software is also available for doing all statistical calculation and preparing regression analysis and ANOVA based on experimental design selection. All that we have to do is to mechanically enter the data in the manner prescribed by the software. Such software save engineers from spending time on statistical calculations and allow them to concentrate more on an experimental designs and experiments itself.

3.6 Experimental Setup

The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed ***tilting cylinder block*** arrangement. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for Pθ−PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit,transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance.

Schematic arrangement of test set up is as shown is figure below:

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Figure 3.1: Engine Test Setup

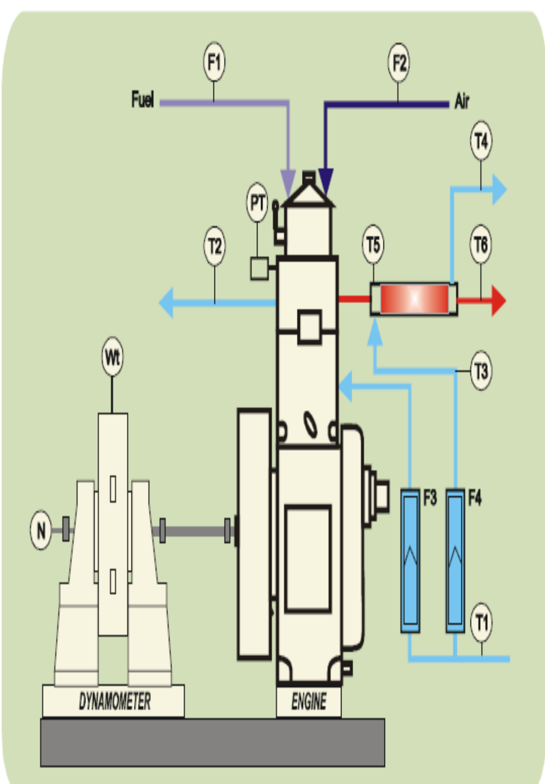


Fig.3.2.Schematic arrangement

Table 3.2: Engine Specifications:

Product : VCR Engine test setup 1 cylinder, 4 stroke, Diesel (Computerized)

Product code: 234
Engine: Make Kirloskar, Type 1 cylinder, 4 stroke Diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5, Modified to VCR engine CR range 12 to 18
Dynamometer: Type eddy current, water cooled, with loading unit
Propeller shaft: With universal joints
Air box: M S fabricated with orifice meter and manometer
Fuel tank: Capacity 15 lit with glass fuel metering column
Calorimeter: Type Pipe in pipe
Piezo sensor: Range 5000 PSI, with low noise cable
Crank angle sensor: Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
Data acquisition device: NI USB-6210, 16-bit, 250kS/s.
Piezo powering unit: Make-Cuadra, Model AX-409.
Digital milivoltmeter: Range 0-200mV, panel mounted
Temperature sensor: Type RTD, PT100 and Thermocouple, Type K
Temperature transmitter: Type two wire, Input RTD PT100, Range 0–100 Deg C, Output 4–20 mA and Type two wire, Input Thermocouple, Range 0–1200 Deg C, Output 4–20 mA
Load indicator: Digital, Range 0-50 Kg, Supply 230VAC
Load sensor: Load cell, type strain gauge, range 0-50 Kg
Fuel flow transmitter: DP transmitter, Range 0-500 mm WC
Air flow transmitter: Pressure transmitter, Range (-) 250 mm WC

The test rig consists of:
1] Loading arrangement
2] A fuel input measuring arrangement
3] An arrangement for measuring the heat carried away by cooling water from engine jacket.
4] An arrangement for measuring the heat carried away by cooling water from exhaust

3.6.1.Loading arrangement

A rope brake dynamometer arrangement with a brake drum couple to the engine shaft and provided with a cooling water arrangement and spring balances. The load can be varied by increasing the rope tension on the brake drum with moving the hand wheel provided on the frame.

3.6.2.A fuel input measuring arrangement

This arrangement consists of a fuel tank of suitable capacity mounted on a stand. The fuel goes to the engine through 50 ml burette. The burette facilitates the measurement of fuel consumption for a definite period with the help of stopwatch.

3.6.3.An arrangement for measuring the heat carried away by cooling water from engine jacket.

Suitable pipefitting is provided for circulating the cooling water into the engine water jacket. For measuring the rate of flow of cooling water, a water meter is provided. With these entire arrangements, we can find the heat carried away by cooling water. The temperature of inlet and outlet water can be directly read from the digital temperature indicator.

3.6.4.An arrangement for measuring the heat carried away by cooling water from exhaust

It consists of exhaust gas calorimeter to measure the heat carried away by exhaust gases. Exhaust gas calorimeter consists of a central tube and an outer jacket. Exhaust gases passes through central tube and water is circulated in outer jacket to get the maximum temperature difference of exhaust gases at inlet and outlet of calorimeter. The volume of water circulation is measured with the help of water meter and stopwatch. Thermocouples are provided to get the inlet and outlet temperature of exhaust gases and water circulated.

3.7.Design of Experiment

1.Selection of control parameters

The following control parameters are selected for the experimental investigation with the three levels.

Table 3.3: Control parameters and their levels

Factors	***Level 1***	***Level 2***	***Level 3***
Blend Ratio (%)	**20**	**30**	**40**
Load (kg)	**5**	**8**	**10**
Speed (rpm)	**1520**	**1510**	**1490**

1.Selection of Taguchi orthogonal array
Factors: 3 and Levels: 3

In this study, a L9 orthogonal array with three columns and nine rows will be used.
No. of Runs: 9

Table 3.4: L9 Orthogonal Array

Experiment No.	***Blend Ratio (%)***	***Load (kg)***	***Speed (rpm)***
1	**20**	**5**	**1520**
2	**20**	**8**	**1510**
3	**20**	**10**	**1490**
4	**30**	**5**	**1520**
5	**30**	**8**	**1510**
6	**30**	**10**	**1490**
7	**40**	**5**	**1520**
8	**40**	**8**	**1510**
9	**40**	**10**	**1490**

1. Setting optimum conditions and prediction of response parameters

The next step in DOE analysis is determining optimal conditions of the control parameters to give the optimum responses. In this work the response variables to be optimized were BTHE, has to be maximized and B.S.F.C. to be reduced as much as possible. Hence the optimum parameter settings will be those that give maximum values of the BTHE and minimum values of B.S.F.C, HC, and NOx. The optimum settings of the parameters were achieved from the S/N Tables of the control parameters.

3.8 Analysis Method

Experiment is planned according to Taguchi's L9 orthogonal array, which has 9 rows corresponding to the number of testes with 3 columns at three levels as shown in table. The first column of table is assigned to Blend proportion i.e. % of cottonseed Biodiesel in diesel, the second to Load, the third column is assigned to Engine Speed. It means a total 9 experiments must be conducted using the combination of levels for each independent factor. This orthogonal array is chosen due to its capability to check the interactions among factors. The experimental results will then transferred in to a Signal to Noise (S/N) ratio. The category the higher-the better for Brake Thermal Efficiency and smaller the better for Brake Specific Fuel Consumption will be used to calculate the S/N ratio for finding optimum set of parameters.

1.Determination of fuel consumption:

Fuel tank is attached with a graduated burette. The valve at the bottom of the tank is closed when fuel consumption rate is to be measured so that fuel is consumed only from the burette. The time taken for 'x' amount of fuel consumption is recorded to measure the fuel consumption rate.

2.Determination of brake power:

The equivalent load 'W' is recorded from the calibrated circular scale incorporated in the dynamometer setup. Brake power is obtained by using the formula:

B.P = $(\pi DWN)/60$

Where,
D is diameter of the brake drum in mm
N is speed of the engine in r/min

3. Determination of brake thermal efficiency

Brake thermal efficiency= (B.P x3600)/ (mf x C.V)

Where,
mf is fuel consumption in kg/h
C.V is calorific value of the fuel used in MJ/kg

4. Grey analysis and weighting factor assigning to the response parameters and obtaining optimal levels of engine performance process parameters. Finally, confirmation experiments will be conducted.

5. Develop Mathematical method for thermal efficiency of engine with biodiesel blends and validate the model with experimental results.

IV. EXPERIMENTATION

4.1 Experimental observations: Observation table for different biodiesel blend at variable load is shown below at compression ratio 18.

Table:4.1 Observations for different blends of fuel

sr. no	blend (%)	comp. ratio	load (kg)	bp (kw)	airflow (kg/h)	fuel flow (kg/h)	a/f ratio
1.	0.00	18	0.1	0.03	30.28	0.52	58.37
			5.00	1.46	29.22	0.51	57.49
			8.00	2.29	28.30	0.50	56.26
			10.0	2.81	27.16	0.49	55.08
2.	20	18	0.1	0.03	29.93	0.48	62.13
			5.00	1.72	29.04	0.46	62.59
			8.00	2.76	28.67	0.46	62.38
			10.0	3.45	28.30	0.46	62.14
3.	30	18	0.1	0.03	29.75	0.52	57.44
			5.00	1.44	28.85	0.51	56.84
			8.00	2.29	28.49	0.50	57.24
			10.0	2.85	28.11	0.48	58.15
4.	40	18	0.1	0.03	29.75	0.54	55.48
			5.00	1.45	28.85	0.53	54.93
			8.00	2.29	28.49	0.52	54.78
			10.0	2.84	28.11	0.51	55.16

V. DESIGN OF EXPERIMENT

5.1 Response table for efficiency

Table 6.1 Response table for efficiency

LEVEL1	BLEND	LOAD	SPEED
1	41.70	26.92	39.76
2	40.23	41.14	40.85
3	38.11	51.98	39.43
DELTA	3.58	23.06	1.42
RANK	2	1	3

Result:-

1. Table shows that as the load increases the speed decrease so the delay time decrease & the efficiency increase.

2. As the blend mixture increase efficiency decrease from DOE.

5.2 Orthogonal Array:-

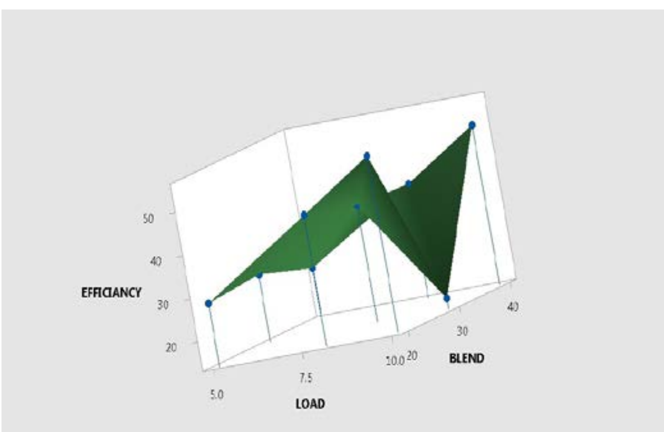
From the below table we can see that 20% blend has the highest efficiency (54.31) & s/n ratio (34.6976) in experiment number 03.

S/N Ratio:- (bigger is the better)

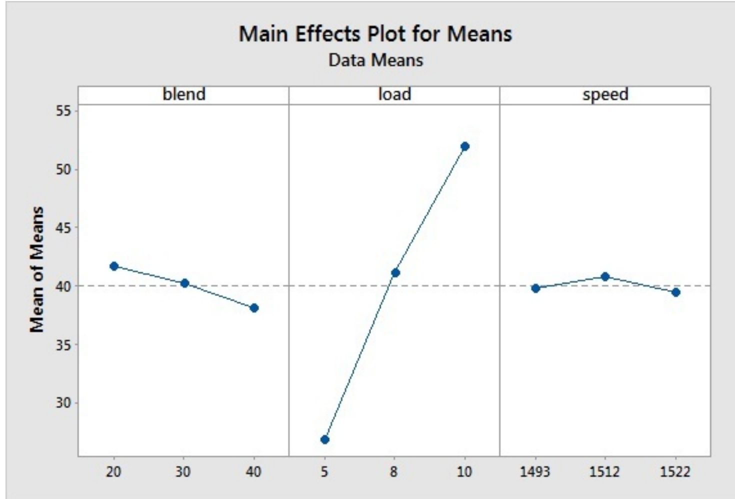
Table 6.2 Optimization for blending mixture

Sr. No	Blend	Load	Speed	Efficiency	S/N Ratio
1	20	5	1522	27.18	28.6850
2	20	8	1512	43.60	32.7897
3	20	10	1493	54.31	34.6976
4	30	5	1512	28.88	29.2119
5	30	8	1493	40.26	32.0975
6	30	10	1522	51.56	34.2463
7	40	5	1493	24.70	27.8539
8	40	8	1522	39.56	31.9451
9	40	10	1512	50.08	33.9933

5.2.1 Comparison Graph



Graph 5.1 Load Vs blend & efficiency



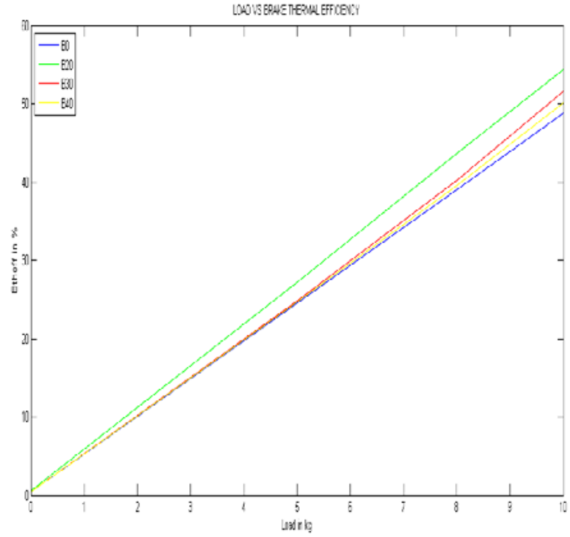
Graph 5.2 Main Effects Plot for Means

VI. RESULTS AND CONCLUSION

6.1.Following are the results obtained from mathematical calculations:-

Table 6.1 Result table for mathematical analysis

Sr. No	B(%)	Load (Kg)	BP (KW)	bsfc (Kg/kwh)	BTh.eff (%)	A/F Ratio
1.	0.00	0.1	0.03	17.56	0.49	58.37
		5.00	1.46	0.35	24.59	57.49
		8.00	2.29	0.22	39.07	56.26
		10.0	2.81	0.18	48.77	55.08
2.	20	0.1	0.03	16.46	0.53	62.13
		5.00	1.72	0.32	27.18	62.59
		8.00	2.76	0.20	43.60	62.38
		10.0	3.45	0.16	54.31	62.14
3.	30	0.1	0.03	17.69	0.49	57.44
		5.00	1.44	0.35	24.88	56.84
		8.00	2.29	0.22	40.26	57.24
		10.0	2.85	0.17	51.56	58.15
4.	40	0.1	0.03	18.27	0.49	55.48
		5.00	1.45	0.36	24.70	54.93
		8.00	2.29	0.23	39.56	54.78
		10.0	2.84	0.18	50.08	55.16



Graph 6.1 Variation of BTh efficiency with load

6.2Variation of Bth efficiency with load:-

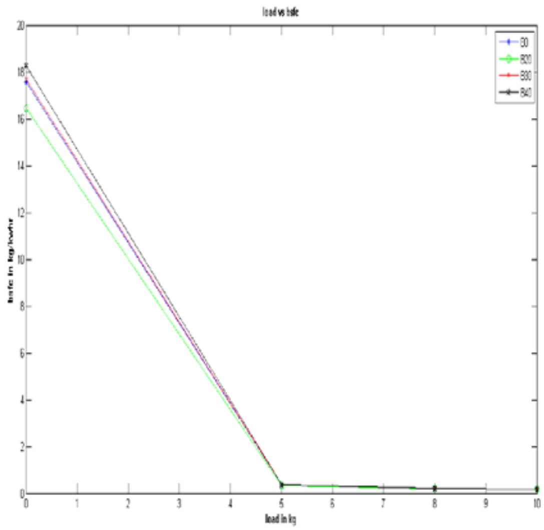
Table6.2 Load and B_{th} at different Blends

Sr. No	Blend (%)	Load (Kg)	BTh.eff (%)
1.	0.00	0.1	0.49
		5.00	24.59
		8.00	39.07
		10.0	48.77
2.	20	0.1	0.53
		5.00	27.18
		8.00	43.60
		10.0	54.31
3.	30	0.1	0.49
		5.00	24.88
		8.00	40.26
		10.0	51.56
4.	40	0.1	0.49
		5.00	24.70
		8.00	39.56
		10.0	50.08

6.3Variation of Bsfc with load:-

Table 6. 3Load and B_{th} at different Blends

Sr. No	Blend (%)	Load (Kg)	BSFC (Kg/kwh)
1.	0.00	0.1	17.56
		5.00	0.35
		8.00	0.22
		10.0	0.18
2.	20	0.1	16.46
		5.00	0.32
		8.00	0.20
		10.0	0.16
3.	30	0.1	17.69
		5.00	0.35
		8.00	0.22
		10.0	0.17
4.	40	0.1	18.27
		5.00	0.36
		8.00	0.23
		10.0	0.18



Graph 6.2 Variation of BTh efficiency with load

VI. CONCLUSIONS

1 From the above experiment we can conclude that B20 is the optimum mixture of cotton seed & orange peel oil in diesel having higher S/N ratio of 34.697.

2 Based on the observations of this experiment, it can be conclude that the performance test done on various blends of biodiesel shows that for 20% blend the overall efficiency of the engine is more as compared to diesel and has break thermal efficiency is higher i.e 54.31% as compare to other blends.

3 Based on the observations of this experiment, it can be concluded that the performance test done on various blends of biodiesel shows that for 20% blend the BSFC of the engine is less i.e 0.16 kg/kwhr as compared to diesel.

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