Performance Optimization of Karanja Biodiesel Engine using Genetic Algorithm

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ABSTRACT

The objective of this work is to optimize the direct injection (DI) single cylinder diesel engine with respect to engine characteristics through experimental investigations and Genetic Algorithm. When biodiesel is used as a substitute for diesel, it is highly essential to understand the parameters that affect the combustion phenomena which will in turn have direct impact on the output. These parameters are: Power (P), Static injection pre`ssure (IP), Injection timing (IT), Fuel fraction (B) and Compression ratio (CR). All the above-mentioned parameters were varied at four levels and the responses brake thermal efficiency (BTHE), brake specific fuel consumption (BSFC), NO_x emissions and HC emissions were studied. The aim of the study is to find a combination of a blend comprising of karanja biodiesel, and other measuring parameters which would increase the performance of diesel engine with minimum emissions from the engine.

Keywords: Biodiesels, Karanja, Diesel engine performance, Brake Thermal Efficiency, Brake Specific Fuel Consumption, Emissions, Genetic Algorithm.

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1. INTRODUCTION

The prodigious growth in the number of vehicles all over the world has led to a rapid rise in the demand for petroleum derivatives. As a result the available resources are depleting at a fast pace, thus destroying the economy of the nation. Biodiesels or vegetable oils seem to be a relevant solution to this growing problem. Biodiesels are kinds of alternative fuels which are similar to conventional or fossil diesels. Some of the popular biodiesels that are currently being considered as substitutes of diesel are Jatropha, Karanja, sunflower, rapeseed. These are non-toxic, renewable, clean burning, biodegradable and environmentally friendly transportation fuels that can be used in neat form or in blends with petroleum derivatives in the diesel engines. Blends of biodiesels as low as B2 have been successful in reducing the amount of toxic carbon based emissions to a great extent. Amongst all the options available, vegetable oil ester Karanja appears to be the best alternative to diesel fuels.

Before using biodiesel as a substitute of diesel, it is very crucial to understand the parameters that affect the phenomenon of combustion which will in turn have direct impact on the thermal efficiency, specific fuel consumption and emissions.

In today's world, direct injection diesel engines have an integral place in developing countries since they play a major role to power agricultural pumps, small power tillers, light surface transport vehicles and other machineries. The basic problem is of increasing demand for high brake power and thermal efficiency and growing deterioration of the fuels. To tackle this problem, modification is very essential in the present engine designs. Optimization approach is one of the basic ways to handle this issue without compromising with the efficiency of the engine. The most common optimization techniques used for engine analysis are response surface method, grey relational analysis, nonlinear regression, genetic algorithm and taguchi method, genetic algorithm technique has been popular for parameter optimization in design of experiments. Genetic Algorithm is a nature inspired optimization method.

The main aim of this project is to investigate the effects of engine parameters on the performance and emission characteristics of a single cylinder diesel engine. Five parameters, namely ,Power (P), Static injection pressure (IP), Injection timing (IT), Fuel Fraction (B) and compression ratio (CR) were varied at four levels and the responses brake power, fuel economy and emissions were investigated. The operating parameters of the engine play an important role in reducing the emissions in the design and are the main factors responsible for enhancing the fuel economy. The parameters of fuel injection like injection valve opening pressure and the compression ratio also have a major influence on emissions and fuel economy. In this work, Genetic Algorithm approach is used to find the effect of design and operating parameters on brake thermal efficiency, specific fuel consumption (BSFC) and emissions.

The effect of the parameters - injection pressure, Compression ratio, Load and engine speed on brake power and smoke were investigated. An increase in injection pressure contributes to fuel economy by improved mixing. Simultaneous reduction of NOx and particulate emissions were observed by combining the varying compression ratio and retarded injection timing. Optimal combination of design and operating parameters were identified that can regulate emissions and improve brake specific fuel consumption. For identifying the optimal combination of injection schedule and fuel spray cone angle, genetic algorithm process was used.

Implementing the use of biodiesels in India will lead to many advantages like green cover to waste land, support to agriculture and rural economy and reduction in dependence on imported crude oil and reduction in air pollution. The Karanja plant has many advantages like the capability of effectively yielding oilseeds from the third years onwards, easy propagation, rapid growth, life span of 40 years and suitability for tropical and subtropical countries like India.

2. LITERATURE REVIEW

Precise optimization of the Direct Injection of a single cylinder is never a simple task, as it could be influenced by a number of performance and emission characteristics. So to begin with, let’s start with the diesel engines. A direct injection diesel engine is the one which directly injects fuel into a combustion chamber. It comprises of: a cylinder, a piston forming the combustion chamber in the cylinder, a fuel injector which starts injection of fuel at a timing not before compression of top dead center of the piston, and finishes the injection of a required amount of fuel during an ignition delay period, an exhaust recirculation passage which decreases the oxygen concentration in the combustion chamber by mixing part of the exhaust gas discharged from the combustion chamber with the intake air of the combustion chamber; and a squish suppressing mechanism which suppresses the squish formed in the combustion chamber. 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. Moving further, in this project the fuel used in the diesel engine is a biodiesel fuel called ‘Karanja Biodiesel’.

Karanja biodiesel falls under the category of non-edible vegetable oils. Among the vegetable oils edible and non-edible oils are used to produce biodiesel. The use of edible is a great concern with food materials. So it is justified to use non edible for the production of biodiesel. Non edible trees can grow in inhospitable condition of heat, low water, rocky and sandy soils. So non-edible oil plants like karanja, jatropha, mahua, neem will be the best choice for the source of biodiesel production. The use of Karanja biodiesel in conventional diesel engines when used alone or with blends with petroleum diesel substantially reduces exhaust emission such as the overall life cycle of carbon dioxide (CO_2), particulate matter (PM), carbon monoxide

(CO), sulfur oxides (SOx) and unburned hydrocarbons(HC) with reducing the green house emission also.

Regarding the power is same to that of diesel engine. The specific fuel consumption is more or less the same. The brake thermal efficiency is slightly on higher side. The aim of the present study is to experimentally investigate the effect of Karanja biodiesel (KOME) on the performance on a diesel engine. The values of the parameters used for optimization in this entire study have been obtained from the following research paper – Investigation on Performance and Emissions of biodiesel engine through optimisation techniques written by Sivaramakrishnan Kaliyamoorthy and Ravikumar Paramasivam. Some of the tools used for such kind of optimization are Taguchi Method, Regression Model, RSM and Genetic Algorithm. The tools used in this optimization process are a few methods from DOE and Genetic Algorithm.

Genetic Algorithms (GA) belong to the more general class of evolutionary computation which is used to describe a broad class of computational methods inspired by the process of natural evolution. GAs are designed to simulate processes in natural systems forced by the principle which says – “survival of the fittest”. As such GAs represent an intelligent exploitation of a random search within a defined search space, where a population of abstract representations of candidate solutions to an optimization problem evolves towards better solutions.

The parameters- Power, Static injection pressure, Injection timing, Fuel Fraction and compression ratio were altered and recorded. Now, these parameters were used to measure and calculate the BTHE ,BSFC, NO_x and HC emissions in order to find a better optimized value for the Single injection diesel engine.The results were then compared to the Taguchi method outputs and a conclusion was drawn on the better results. As in which optimization technique is more reliable and practically applicable.

3. PROBLEM STATEMENT

The objective of this project is aimed at, optimizing the direct injection (DI) single cylinder diesel engine using Karanja biodiesel, with the performance and emission characteristics of the engine as the measuring parameters. The optimization process has been conducted on the experimental results taken from the research paper by using Genetic Algorithm.

The five parameters to be considered are Power (P), Static injection pressure (IP), Injection timing (IT), Fuel Fraction (B) and compression ratio (CR). All the above mentioned parameters were varied at four levels and the responses- Brake thermal efficiency (BTHE), Brake specific fuel consumption (BSFC) ,NO_x and HC emissions were investigated. As far as the I.C engines are concerned the thermal efficiency and emission characteristics are the important parameters for which the other design and operating parameters have to be optimized. The main objective of this project is to lower the fuel consumption of the single injection diesel engine and to enhance its fuel economy and efficiency. To achieve the above mentioned objective, the tools used to perform the Genetic Algorithm technique were Mini Tab and MATLAB.

4. OVERVIEW OF BIODIESEL PRODUCTION

Biodiesel is an alternative fuel for diesel engines that is produced chemically by reacting a vegetable oil or animal fat with an alcohol such as methanol. This reaction requires a catalyst, a strong base, such as sodium or potassium hydroxide, and produces new chemical compounds called methyl esters. It is these esters that have come to be known as biodiesel. Because its primary feedstock is a vegetable oil or animal fat, biodiesel is generally considered to be renewable. Since the carbon in the oil or fat originated mostly from carbon dioxide in the air, biodiesel is considered to contribute much less to global warming than fossil fuels.

Diesel engines operated on biodiesel have lower emissions of carbon monoxide, unburned hydrocarbons, particulate matter, and air toxics than when operated on petroleum-based diesel fuel At current production levels, biodiesel requires a subsidy to compete directly with petroleum-based fuels. However, federal and state governments are providing incentives that encourage the rapid growth of the biodiesel industry. Current production levels are 20–25 million gallons/year, but achieving current European levels of 500 million to 1 billion gallons/year should be feasible. Although biodiesel cannot entirely replace petroleum-based diesel fuel, there are at least five reasons that justify its development.

1. It provides a market for excess production of vegetable oils and animal fats.

2. It decreases, although will not eliminate, the country’s dependence on imported petroleum.

3. Biodiesel is renewable and does not contribute to global warming due to its closed carbon cycle. A life cycle analysis of biodiesel showed that overall CO2 emissions were reduced by 78% compared with petroleum-based diesel fuel [2].

4. The exhaust emissions of carbon monoxide, unburned hydrocarbons, and particulate emissions from biodiesel are lower than with regular diesel fuel. Unfortunately, most emissions tests have shown a slight increase in oxides of nitrogen (NOx).

5. When added to regular diesel fuel in an amount equal to 1–2%, it can convert fuel with poor lubricating properties, such as modern ultra-low-sulfur diesel fuel, into an acceptable fuel.

Biodiesel is produced through a process known as trans-esterification. By chemically converting oils and fats to methyl esters, the glycerol could be separated because it is insoluble in the esters. The glycerol has a much higher density so it is easily removed by settling or centrifuge. The glycerol-free methyl esters were then reacted with alkali to form soap. Bradshaw received a patent for a process that added about 1.6 times the theoretical amount of an alcohol, such as methanol, which contained 0.1 to 0.5% sodium or potassium hydroxide, to an oil or fat. When performed at 80 8C, this process provided 98% conversion to alkyl esters and high-quality glycerol. These patents contain the following observations about the trans-esterification process:

- Excess alcohol of more than 1.6 times the stoichiometric amount is required for complete reaction.
- The amount of alcohol used can be reduced by conducting the reaction in steps, where part of the alcohol and catalyst are added at the start of each step, and the glycerol is removed at the end of each step.
- Besides methanol, other alcohols can be used including ethanol, propanol, isopropanol, butanol, and pentanol.
- Water and free fatty acids inhibit the reaction. Higher alcohols are particularly sensitive to water contamination.

Acid catalysts can be used for the trans-esterification of oils to alkyl esters, but they are much slower than alkali catalysts. Knothe has described how ethyl esters were proposed as diesel fuel substitutes as early as 1937 in the Belgian Congo. Widespread investigation of these esters did not occur until the late 1970s and early 1980s when high petroleum prices inspired extensive research into alternative fuels. Vegetable oils were proposed as diesel fuels but were found to be problematic due mostly to their greater viscosity. Problems were found with piston and injector deposits and crankcase oil dilution and resultant oil thickening.

5. DESIGN OF EXPERIMENTS

The technique of defining and investigating all possible conditions in an experiment involving multiple factors is known as the design of experiments (DOE), also known as Factorial Design.

Before giving further insight into the concept of Factorial Design, it is of significant importance to first define some useful terms.

1. **Treatment**

A **TREATMENT** is an operation that designers administer to experimental units. For instance, a dirty cloth sample is treated with two different detergents to see which washes the dirt more effectively.

2. **Level**

Treatments are administered to experimental units by **LEVEL**. Level implies the magnitude or amplitude of the units.

3. **Factor**

A **FACTOR** of an experiment is a controlled independent variable, whose levels are set by the designer or experimenter. It is a general type or category of treatments. Different treatments constitute different levels of a factor.

Thus treatments are combinations of levels of the factors.

Hence a **FACTORIAL** experiment is an experiment whose **DESIGN** consists of multiple factors, each with discrete levels and whose experimental units take on all possible combinations of these levels across all such factors.

5.1 ILLUSTRATION:

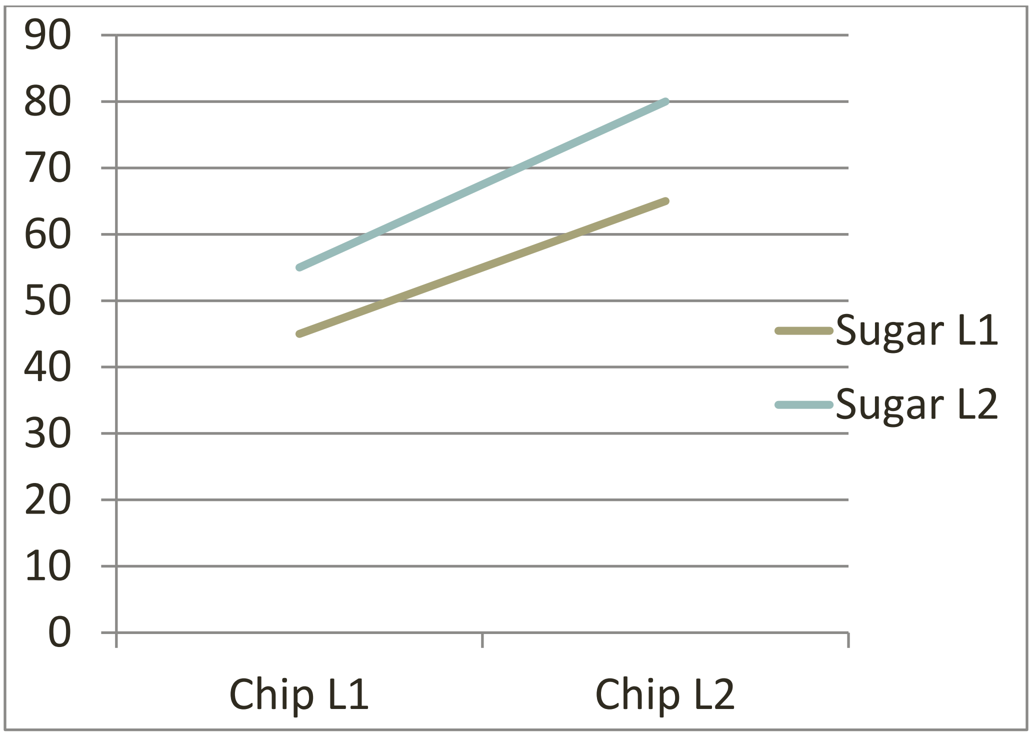
Consider a snack food company planning to introduce a new chocolate chip cookie in the market. The product designers have standardized all other ingredients except the amount of sugar and chocolate chips. Two levels of chips, C1 and C2, and two levels of sugar, S1 and S2, were selected (subscripts 1 and 2, respectively, refer to the low and high levels of each factor). To select the best combination of these ingredients that appeal most to potential customers, the market research group decided to conduct a survey of customer preference.

Examination of customer response shows a 10% (55 – 45) increase in preference for sugar level S2 at the low level (C1) of chocolate chips, but the response increases to 15% (80 – 65) when more chips (C2) are used. These increases are called the simple effect of sugar. On the other hand, for the higher amount of chips, the taste preference increased from 45% to 65% at sugar level S1 and further increased to 80% with the higher sugar level S2.

CHOCOLATE LEVEL CHIPS	**SUGAR LEVEL**		**MEAN**	**MEAN RESPONSE (CHOCOLATE CHIPS) (C2– C1)**
	S1	**S2**		
C1	**45**	**55**	**50.0**	**22.5**
C2	**65**	**80**	**72.5**	**22.5**
MEAN	**55.0**	**67.5**	**61.25 GRAND MEAN**	

MEAN RESPONSE **(SUGAR) (S2 – S1)**	**12.5**		

This is one of the simplest cases of design of experiments. It involves two factors (chips and sugar) at two different levels (high and low) that affect the taste of cookies. Such an experiment is described as a 2 × 2 factorial experiment. There are four (2^2) possible treatments or combinations.



The mean response, that is, the difference between the average effects at two levels of sugar (12.5%), is called the main effect of sugar. Similarly, the main effect for chocolate chips is 22.5%.

In the above example there were only two factors, each at two different levels. It would be rather easy to manufacture four types of cookies reflecting all possible combinations of the factors under study and to subject them to a market survey.

For a full factorial design, the number of possible designs, N is

N = L^m

Where L is the number of levels of each factor and m is the number of factors.

5.2 ADVANTAGES OF FACTORIAL DESIGN

1. Factorial experiments are used to simplify the experiment.
2. Fractional factorial experiments investigate only a fraction of all possible combinations. This approach saves considerable time and money.

5.3 DISADVANTAGES OF FACTORIAL DESIGN

1. The experiments become unwieldy in cost and time when the number of variables is large.
2. Two designs for the same experiment may yield different results.
3. The interpretation of the experimental results with a larger number of factors may be difficult due to lack of clear design and analysis guidelines.

To overcome the problems and challenges occurred during the use of Factorial Design and with an aim to achieve greater optimization, new techniques and tools have been developed in course of time with more simplified processing and favorable outputs.

Before defining the tools of DOE and moving on, it is imperative to understand few statistical terms:

1. **Main Effect**

MAIN EFFECT is the simple effect of a factor on a dependent variable. It is the effect of the factor alone averaged across the levels of other factors.

2. **Interaction**

An **INTERACTION** is the variation among the differences between means for different levels of one factor over different levels of the other factor.

3. **Analysis of Variance (ANOVA)**

ANALYSIS OF VARIANCE (**ANOVA**) is a collection of statistical models used to analyse the differences among group means and their associated procedures for instance, variance.

4. **Randomization**

RANDOMIZATION is the process by which experimental units (the basic objects upon which the study or experiment is carried out) are allocated to treatments; that is, by a random process and not by any subjective and hence possibly biased approach. The treatments should be allocated to units in such a way that each treatment is equally likely to be applied to each unit.

5. **Complete Random Design**

The structure of the experiment in a **COMPLETELY RANDOM DESIGN** is assumed to be such that the treatments are allocated to the experimental units completely at random.

5.4 TAGUCHI'S DESIGN OF EXPERIMENTS

Aiming to make the DOE simplified, more attractive and accessible, Dr Genichi Taguchi of Japan at the time of World War II proposed an innovative method with following considerations for application of the technique:

1. **Definition of Quality**

Taguchi defined quality in terms of minimum loss to society, which statistically means consistency of performance. Consistency is achieved when performance is close to the target with least variation. To improve quality, Taguchi proposed a two-step optimization approach:

- Find the factor-level combination that reduces performance variability.
- Adjust the factor levels that bring performance closer to the target.

2. **Standardized DOE**

Taguchi utilized a special set of tables, called orthogonal arrays which represent the smallest fractional factorials and are used for most common experiment designs.

3. **Robust Design Strategy**

To make products and processes insensitive to the influence of uncontrollable (noise) factors, Taguchi incorporates a formal way to include noise factors in the experiment layout leading to a favorable performance with the mean close to the target and reduced variation around the mean.

4. **Loss Function**

The mathematical formula associated with the concept of the loss function proposed by Taguchi allows a simple way to quantify the improvements in monetary units.

5. **Signal-to-noise (S/N) analysis**

For analysis of results from multiple-sample tests, use of signal-to-noise ratios instead of the results makes the analysis of DOE results much easier. In addition, the logarithmic transformation of the results in terms of S/N ratios empowers the prediction of improvement in performance from the analysis.

5.5 TAGUCHI'S PHILOSOPHY

The whole of Taguchi's design of experiment is based upon his philosophy solely comprised of three important principles:

- Quality should be designed into the product and not inspected into it.
- Quality is best achieved by minimizing the deviation from a target. The product should be so designed that it is immune to uncontrollable environmental factors.
- The cost of quality should be measured as a function of deviation from the standard, and the losses should be measured system-wide.

Taguchi believed that the better way to improve quality was to design and build it into the product. Quality improvement starts at the very beginning, that is, during the design stages of a product or a process, and continues through the production phase.

Taguchi's second concept deals with actual methods of improving the quality of products. He contended that quality is directly related to the deviation of a design parameter from the target value, not to conformance to some fixed specifications.

The third concept calls for measuring deviations from a given design parameter in terms of the overall life cycle costs of the product. These costs would include the cost of scrap, rework, inspection, returns, warranty service calls, and/or product replacement. These costs provide guidance regarding the major parameters to be controlled.

5.6 ADVANTAGES OF TAGUCHI DESIGN

- Easily applied to a large amount of data parameters
- Reliable method of optimization

5.7 DISADVANTAGES OF TAGUCHI DESIGN

- Large number of experimental runs are required
- Time consuming method of optimization

6. NATURE INSPIRED TECHNIQUES

The following text gives a brief overview about certain nature inspired algorithms used in the optimization of a given objective. Nature inspired algorithms are among the most powerful algorithms for optimization since they scale well to higher dimensional problems. They are robust with respect to noisy evaluation functions and the search space is very large, with successive enhancements.

Some of the popular nature inspired techniques are as follows:

- **Firefly Algorithm** - Flashing characteristics of fireflies is used to develop firefly -inspired algorithm. Fireflies are a species of insects producing short and rhythmic flashes. The pattern observed for these flashes is unique for most of the times for a specific species. Also it is a known fact that the intensity of light varies inversely with the square of distance, so if an object is closer, it will have a higher intensity compared to the object being farther. The algorithm uses three idealized rules:

    1. All the fireflies are unisex so it means that one firefly is attracted to other fireflies irrespective of their sex.
    2. Attractiveness and brightness are proportional to each other, so for any two flashing fireflies, the less bright one will move towards the one which is brighter. Attractiveness and brightness both decrease as their distance increases.
    3. The brightness of a firefly is determined by the view of the objective function.

For a maximization problem, the brightness is simply proportional to the value of the objective function.

- **Bat Algorithm** – Bat algorithm is a global optimization technique inspired by the echolocation behaviour of micro bats with varying pulse rates of emission and loudness. The algorithm is based upon the idealization of the echolocation of micro bats:

    1. Each virtual bat flies randomly with a velocity v_i at position (solution) x_i with a varying frequency or wavelength and loudness A_i
    2. As it searches and finds its prey, it changes frequency, loudness and pulse emission rate r.
    3. Selection of the best continues until certain stop criteria are met.

- **Cuckoo Search** – Cuckoo Search is an evolutionary optimization algorithm that is inspired by the aggressive reproduction strategy of the cuckoo bird, by which mature cuckoos lay their eggs in the nests of other host birds or specie

Cuckoo Search is basically based on three idealized important rules.

1. Each cuckoo lays one egg at a time and dumps its egg in a randomly chosen nest.
2. The best nest with high-quality eggs will carry over to the next generation.
3. The number of available hosts' nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability $p_a \varepsilon [0, 1]$.

The possibility is that the host bird can either throw the egg away or abandon the nest and build a completely new nest.

7. GENETIC ALGORITHM

Genetic Algorithm is a nature inspired technique which mimics the process of natural selection. It is based on the theory proposed by Darwin which states that **ONLY THE FITTEST WILL SURVIVE**, since in nature, competition among individuals for scanty resources results in the fittest individuals dominating over the weaker ones. Genetic Algorithm generates solutions to optimization problems using methods inspired by natural evolution like, inheritance, mutation, selection and crossover.

The algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm randomly selects individuals from the current population and uses them as parents to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution.

Genetic algorithm differs from the classical algorithm as it:

1. Generates a population of points during each iteration. The best point in the population approaches the optimal solution.
2. Selects the next population by computation which uses random number generators.
3. Searches for global maxima or minima depending upon the optimization problem rather than confined or local minima.
4. Generates robust results.

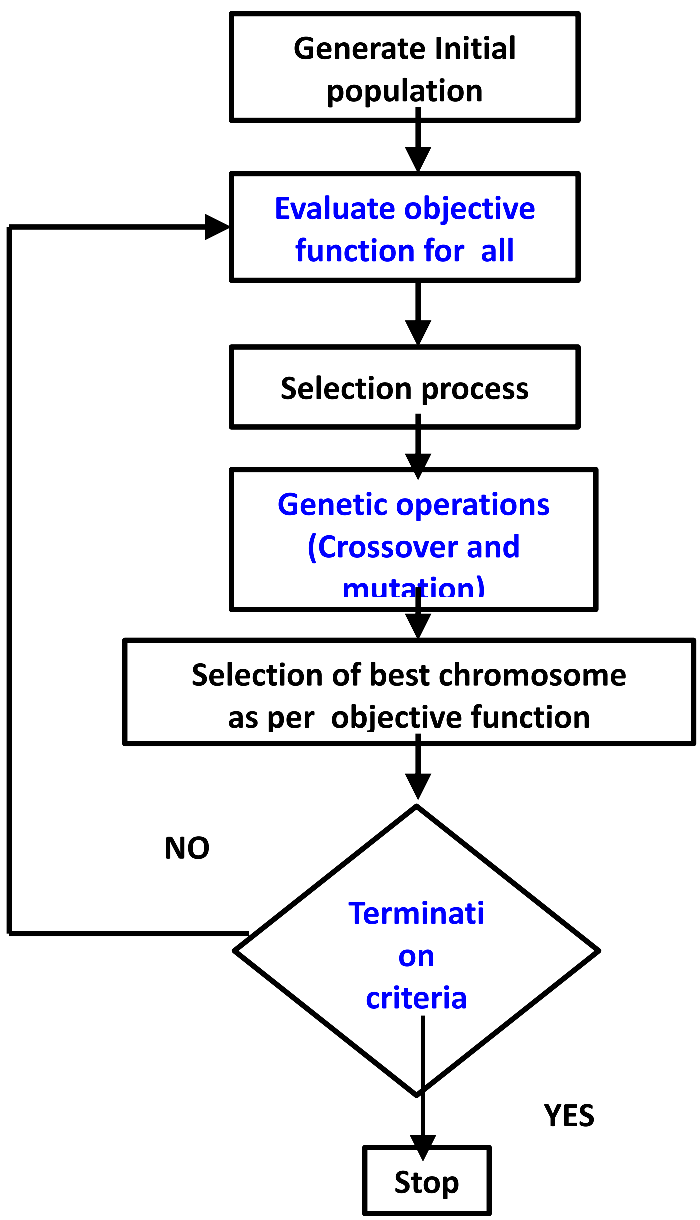
It is reasonable to introduce some biological terms for a better understanding of the principle of Genetic Algorithm (GA):

- **Inheritance** – Inheritance is the passing of traits and characteristics from parents to offspring through reproduction, either sexually or asexually.
  Through inheritance variations exhibited by individuals can further accumulate and causes some species to evolve through the natural selection and evolution.
- **Mutation** - A mutation is a change that occurs in our DNA sequence, either due to mistakes when the DNA is copied or as the result of environmental factors. The change is permanent and the damaged DNA cannot be repaired. Mutation also leads to an evolution of species possessing different traits, thus introducing diversity.

- **Selection** - Selection is a process where a section of population is chosen based on certain parameters the selected individuals satisfy. A selected section of population is the subject which will be treated according to the experimental conditions to get the desired results.
- **Crossover** – Crossover or Chromosomal crossover is the exchange of genetic material between homologous chromosomes that results in recombinant chromosomes during sexual reproduction. Crossover usually occurs when matching regions on matching chromosomes break and then reconnect to the other chromosome.

Genetic Algorithms simulate the survival of the fittest among individuals over consecutive generation for solving a problem. Each generation consists of a population of character strings that are analogous to the chromosome that we see in our DNA. Each individual represents a point in a search space and a possible solution. The individuals in the population are then made to go through a process of evolution.

The following flow chart depicts the process of Genetic Algorithm



GAs are based on an analogy with the genetic structure and behaviour of chromosomes within a population of individuals using the following foundations:

- Individuals in a population compete for resources and mates.
- Those individuals most successful in each 'competition' will produce more offspring than those individuals that perform poorly.
- Genes from `good' individuals propagate throughout the population so that two good parents will sometimes produce offspring that are better than either parent.
- Thus each successive generation will become more suited to their environment.

Search Space – Search space is the set of population on which the experiments are done to get the optimized results. A search space is defined by two bounds namely lower bounds and the upper bounds which comprise the range of the search space.

Lower Bounds – Lower limit of the parameter values

Upper Bounds - Higher limit of the parameter values

7.1 Optimization using Genetic Algorithm

- The tool used to conduct optimization using Genetic Algorithm is Matlab

- In order to carry out the optimization a fitness function is defined which gives the relationship between the response variables needed to be optimized and independent factors or parameters.

- The relationship between the response variable(y) and independent factors(x1, x2…xn) is an equation of regression generated using regression analysis in a software called Minitab or MS Excel.

Regression analysis provides a method of linking the performance variable with the design parameters through a mathematical model if more than one design parameter affecting the response parameters is there. This is termed as multiple regressions. When there are five design parameters involved the regression model becomes,

$$Y=\beta 0 + \beta 1XI + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5$$

- The values of the coefficients are calculated using the table consisting of discrete response variable values for discrete values of the design parameters. Least square method is one of the methods used to calculate the values of the coefficients.

- Once the equation of response variable in terms of design factors is obtained, genetic algorithm tool is run on MATLAB, by specifying the range of the search space and the desired optimum values are obtained.

7.2 ADVANTAGES OF GENETIC ALGORITHM

- There are multiple local optima
- The objective function is not smooth (so derivative methods can not be applied)
- The number of parameters is very large
- The objective function is noisy or stochastic

7.3 DISADVANTAGES OF GENETIC ALGORITHM

- No guarantee of finding global maxima
- Time taken for convergence
- Other complex aspects
- Incomprehensible Solutions

8. Analysis and Optimization

8.1 Control Parameters

The following control parameters given in the table __ were selected for investigation as they have a significant influence on the brake power and fuel economy. These parameters were varied and the experiments conducted are taken from the research paper.

Controlled Factors	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Compression Ratio	17.5	17.7	17.9	18.1
Static Injection Pressure (bar)	190	210	220	230
Injection Timing (bTDC)	23	25	27	29
Fuel Fraction , %	10	20	30	50
Power (kW)	3.64	4.16	4.68	5.2

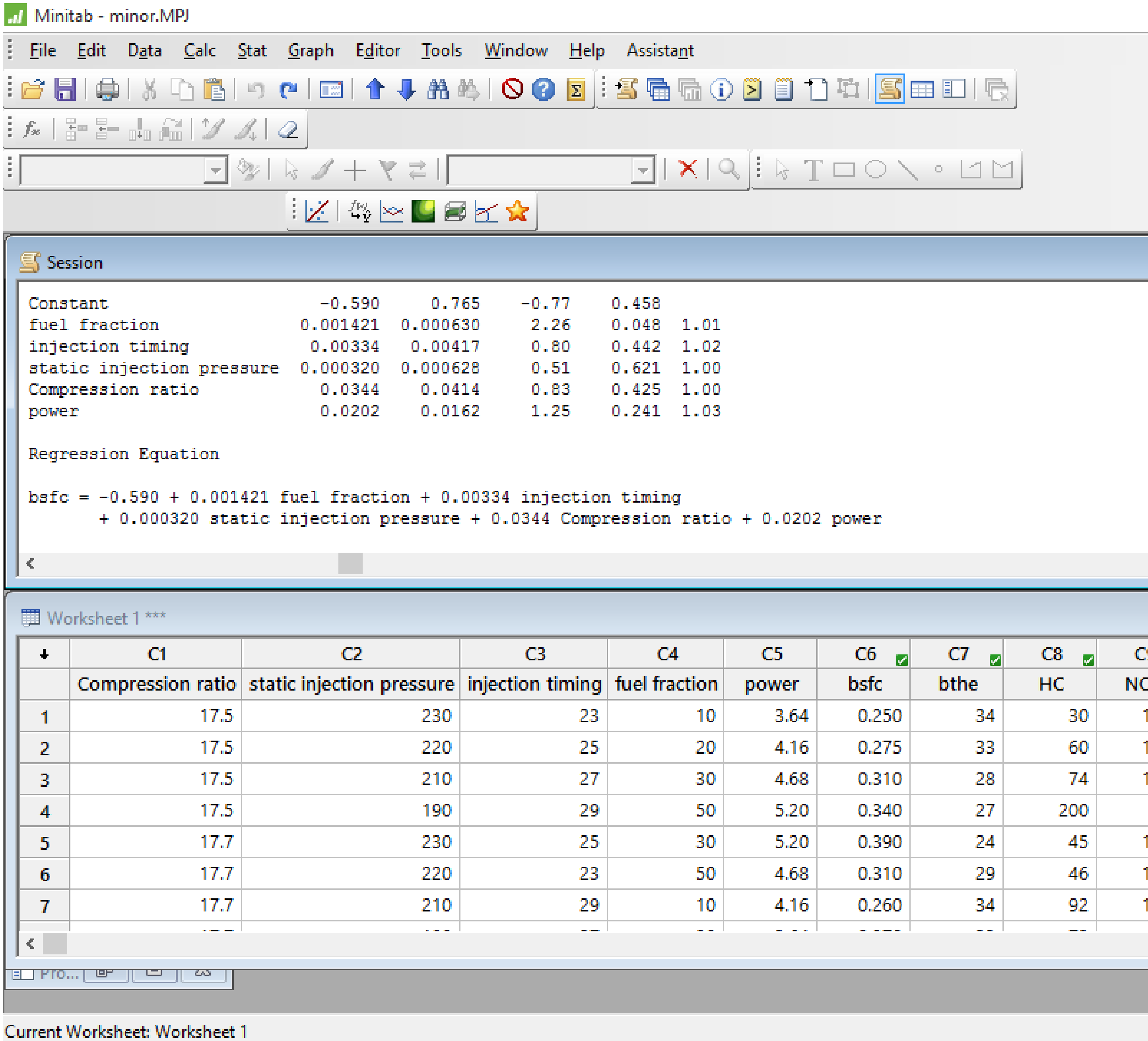
Table Levels for Design Parameters:- Experimental Results

Run Number	Compression Ratio	Static Injection Pressure	Injection Timing	Fuel Fraction	Power	Brake Specific Fuel Consumption	Brake Thermal Efficiency	HC Emissions	NO_x Emissions
1	17.5	230	23	10	3.64	0.25	34	30	1572
2	17.5	220	25	20	4.16	0.275	33	60	1300
3	17.5	210	27	30	4.68	0.31	28	74	1057
4	17.5	190	29	50	5.2	0.34	27	200	690
5	17.7	230	25	30	5.2	0.39	24	45	1606
6	17.7	220	23	50	4.68	0.31	29	46	1300
7	17.7	210	29	10	4.16	0.26	34	92	1122
8	17.7	190	27	20	3.64	0.27	33	73	627
9	17.9	230	27	50	4.16	0.31	30	40	1258
10	17.9	220	29	30	3.64	0.37	26	50	1100
11	17.9	210	23	20	5.2	0.27	34	123	1133
12	17.9	190	25	10	4.16	0.26	35	134	662
13	18.1	230	29	20	4.16	0.3	30	33	1720
14	18.1	220	27	10	5.2	0.3	31	100	1300
15	18.1	210	25	50	3.64	0.32	29	41	800
16	18.1	190	23	30	4.68	0.35	27	260	625

8.2 Developing a multiple regression model

A mathematical model is made linking the dependent variables BTHE, BSFC, NO_x and HC to the independent variables or the design and control parameters i.e. compression ratio , static injection pressure, injection timing, fuel fraction and power is made . This is done using the

Minitab Regression tool.



The regression models are given by :

Y (BTHE) = -1.353A-0.032B -0.301C-0.1278D-1.586E+79.60

Y (BSFC) = 0.0344A+0.00032B+0.0033C+0.0014D+0.0202E-0.59

Y (NOx) = -121.50 A+22.07B +1.74C-4.77D+99.95E-1764

Y (HC) = 40.5 A-3.12 B-1.64C-0.170 D+43.9 E-115

Where A, B, C, D , E are compression ratio, static injection pressure, injection timing, fuel fraction and power respectively.

These equations are then fed into MATLAB and applied in Genetic Algorithm.

Multi Objective Optimization Using Genetic Algorithm

To obtain an optimal combinations of engine parameters considering Performance and emissions Multioptimization techniques is used.

8.3 Range

The range of the control variables are noted and specified which corresponds to the search space in which the tool carries out the optimization at the time of applying Genetic Algorithm.

Control Variables	Lower Bound	Upper Value
Compression Ratio	17.5	18.1
Static Injection Pressure	190	230
Injection Timing	23	29
Fuel Fraction	10	50
Brake Power	3.64	5.2

8.4 Weighing Factor

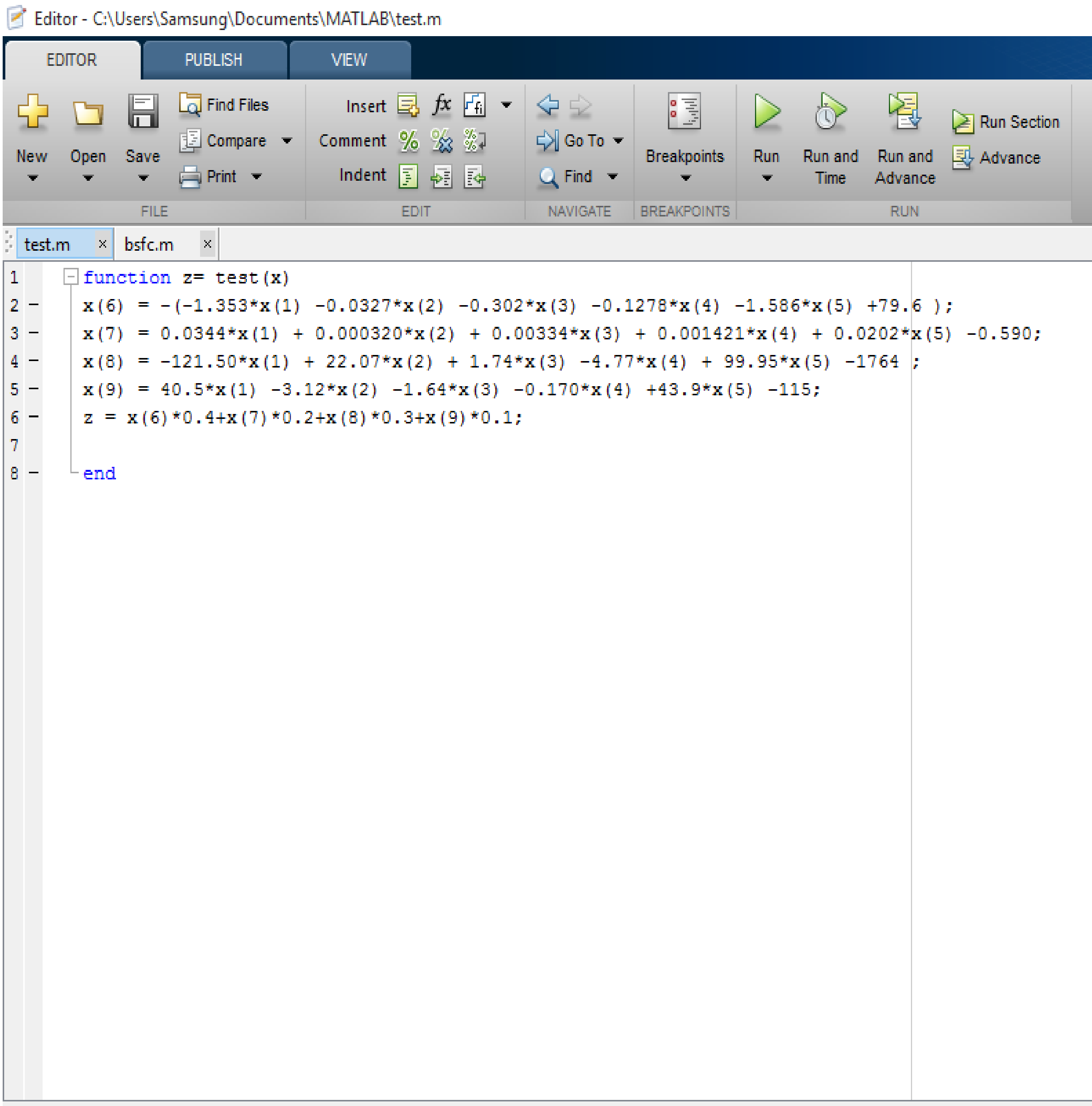
The sum of the weighing factors for all the response variables should be unity and the weighting factor assigned to each particular response variable is determined on the basis of its relative importance.

S.No	Response Variable	Weighing Factor
1	BTHE	0.4
2	BSFC	0.2
3	NO_x	0.3
4	HC	0.1

The four equations obtained above by regression analysis are coded into MATLAB. A fitness function "test" is defined such that z is a function of x.

x(1) , x(2) , x(3) , x(4) , x(5) represent the control variables compression ratio, static injection pressure, injection timing, fuel fraction and power respectively.

The equations for brake thermal efficiency, brake specific fuel consumption, NO_x emissions and HC emissions are represented by x(6) , x(7), x(8), x(9)

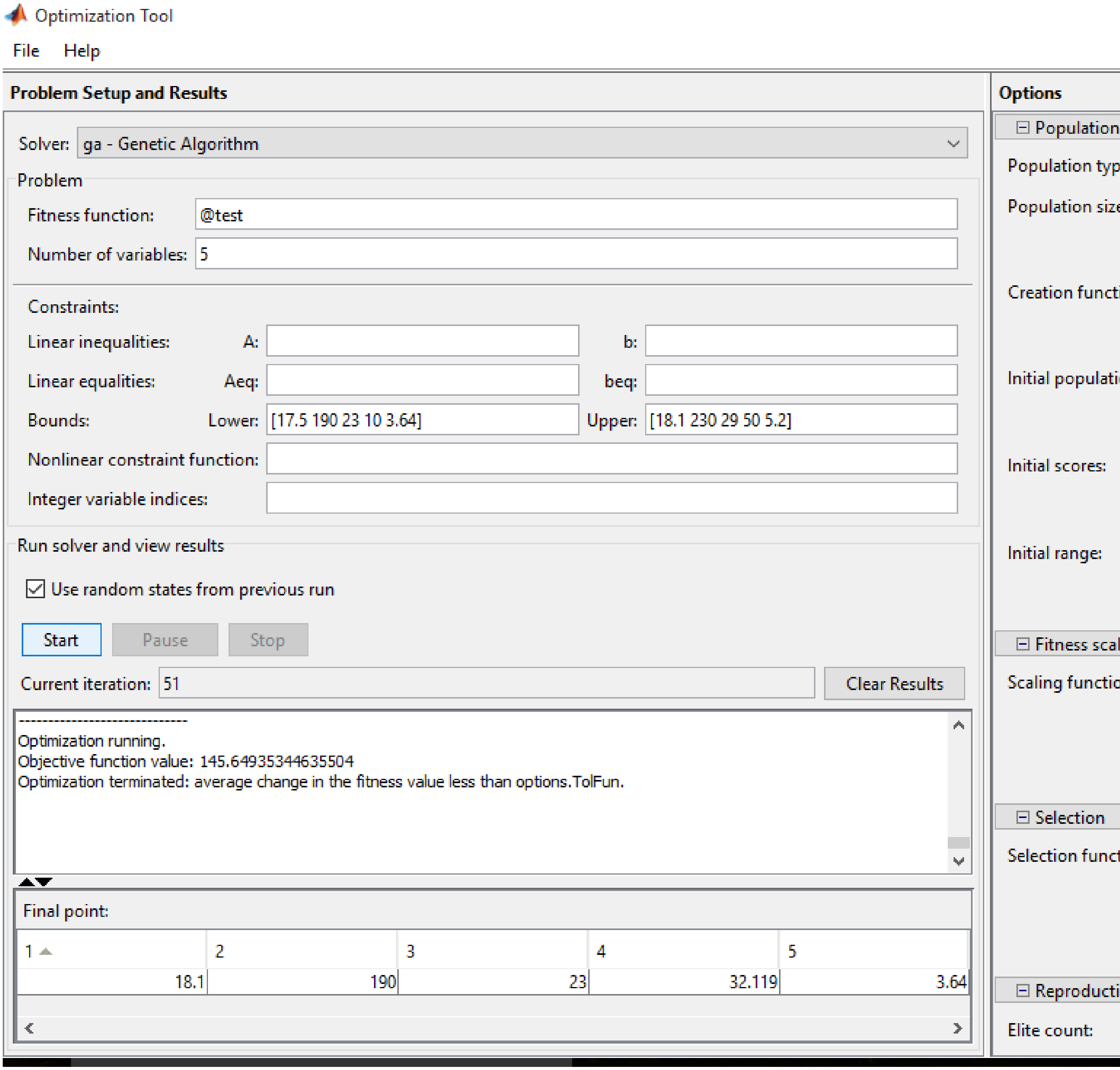


The fitness function z is calculated using the following values

Z = x(6) * W1 + x(7) * W2 + x(8) * W3 + x(9) * W4

Where W1 , W2 , W3 and W4 are the weighing factors f.

The optimization tool is run on MATLAB in which we have to specify our fitness function “test”, number of control variables and the lower and upper bound of all the control variables.



9. RESULTS

It is observed that the following combination of parameters is the optimal combination which achieves multiple performance characteristics of the engine.

Compression Ratio	18.1
Static Injection Pressure (bar)	190
Injection Timing (bTDC)	23
Fuel Fraction (%)	32.12
Power (kW)	3.64

Table ______ Value of control variables

These values of control variables are put into the regression model equations to obtain values the four response variables.

S.No	Response Variable	Values
1	Brake Thermal Efficiency	32.0766 %
2	Brake Specific Fuel Consumption	0.2894 kg/kw-hr
3	NO_x Emissions	481.0234 PPM
4	HC Emissions	141.7848 PPM

These response values are compared with those values obtained by using Taguchis Method from the research paper.

S.No	Response Variable	Predicted value using GA	Predicted Value Using Taguchi
1	Brake Thermal Efficiency	32.0766 %	32 %
2	Brake Specific Fuel Consumption	0.2894 kg/kw-hr	0.298 kg/kW-hr
3	NO_x Emissions	481.0234 PPM	1249 PPM
4	HC Emissions	141.7848 PPM	24 PPM

10. CONCLUSION

The genetic algorithm approach analysis has been carried out for optimizing the performance of karanja biodiesels engine. The various input parameters have been optimized using SNR. The Higher –the better quality characteristic has been been used for maximizing the brake thermal efficiency and lower-the-better has been used to minimize the BSFC and Emissions. The compression ratio was found to be the most significant parameter followed by injection timing. Based on this study, it can be concluded that BTHE, BSFC and Emissions of diesel engine depend upon biodiesel blend, compression ratio, Nozzle pressure and injection timing. It was found that a diesel engine operating at a compression ratio -17.7, Pressure 230 bar, Injection timing of 27° bTDC, Biodiesel –diesel blend B20. and Brake power-3.64 kW achieves the optimum engine performance. The results are well supported by the findings of our confirmatory test.

11. FUTURE SCOPE OF WORK

The parameters which have been optimized in this study, if those are used with the optimized values in the concerned single – cylinder diesel engine, it will lead to preservation of a vast amount of resources along with a better efficiency and fuel economy of the diesel engine.

Further after this study, we intend to carry forward our results and test the engine parameters using various other optimization methods to get a more accurate and reliable set of values to further improve the performance characteristics.

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