Analysis and Performance Optimization of Variable Compression Ratio Diesel Engine using Canola Oil Based Biodiesel

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INTRODUCTION

Alternative or non-conventional fuels, are the combustibles material and can be used as fuels like conventional fuels, like fossil fuels [1]. Compressed Natural Gas (CNG) [2], Liquefied Petroleum Gas (LPG) [3], Ethanol [4], Biogas [5] and Biofuels [6, 7] etc. are known as alternative fuels. Biofuels are derived from biomass i.e. plant material or animal waste. Since biomass is readily available they are called as renewable energy sources. Biodiesels possess similar characteristics as compared to conventional Diesel. Soybean oil [8, 9], corn oil [10, 11], sunflower oil [12], rapeseed oil [13, 14] and palm oil [15, 16], algae [17, 18], Jatropha [19, 20] are other major resources of biodiesel worldwide. Recycled grease [21, 22], oils [23] as well as animal fats [24] can also be used for production of biodiesel. Biodiesel is compatible with Diesel and can be blended in different concentration [12] e.g. blend B40 represents 40% Biodiesel mixed with 60% diesel. Further no engine modification is required for experimentation. In present work Canola Oil Based Biodiesel (COB) is considered because canola seeds production is in greater amount than other oil seed crops, leading to increased canola oil production. Canola oil is manufactured through the process of transesterification; oil is further treated with alcohol to remove the glycerin. The most common blends are B20, B40 and B60. Properties of COB are summarized in Table 1.

EXPERIMENTAL SETUP

A Computerized Variable Compression ratio (4stroke, single cylinder, VCR, Product Code 234) diesel engine fitted with Eddy current type dynamometers (manufactured by Apex Innovation, Sangli) is used for conducting experimentation. Initially VCR engine is fueled with pure diesel to start the engine and further it is operated on biodiesel. Canola based biodiesel was purchased from SVM Agro Processor, Nagpur, India. Figure 1 shows experimental setup and Table 2 shows the VCR engine specifications.

OPTIMIZATION OF VCR ENGINE PERFORMANCE

Taguchi method was developed a method for the design of experiments based on well-structured guidelines. In this

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TABLE 1. Properties of canola oil based biodiesel (ref. SVM agro pvt. Ltd)

| Sr. No | Parameter                  | Units | Results  | Standard  | Protocol          |
|--------|---------------------------|-------|----------|-----------|-------------------|
| 1      | Density:15°C              | kg/m³ | 885.0    | 860-900   | IS:1448(P:16/32)  |
| 2      | Kinematic Viscosity at 40°C| Cst   | 8.00     | 2.5-8.0   | IS:1448(P:25)     |
| 3      | Flash Point (PMCC)        | °C    | 140      | 120min    | IS:1448(P:21)     |
| 4      | Water Content             | mg/kg | 60       | 500max    | IS:1993           |
| 5      | Acid Value                | mgKOH/g | 0.5     | 0.5max    | IS:1448(P:1)-1971 |
| 6      | Gross calorific value     | kcal/kg | 9550     | -         | -                 |

Figure 1. Computerized VCR engine test setup

TABLE 2. VCR engine specification

| Sr. No | Information                      | Specification |
|--------|----------------------------------|---------------|
| 1      | Manufacturer                     | Kirloskar Oil Engines Ltd, India |
| 2      | No. of Cylinders                 | 1             |
| 3      | No. of Strokes                   | 4             |
| 4      | Fuel                             | Diesel        |
| 5      | Rated Power                      | 3.5 kW @1500 rpm |
| 6      | Compression Ratio Range          | 12 ° 18.1     |

method set of orthogonal arrays are used for conducting minimum number of experiments which may predict full information about the factors that are affecting the performance parameter with their percentage of contribution [25-27]. The important point need to be considered while constructing the orthogonal arrays is the selection of levels and combinations of input parameters for each experiment. Table 3 shows the selection of parameters and levels for optimization work.

Selection of orthogonal array and experimental results

In present work, three input parameters with three levels are selected and L27 orthogonal array is considered. Total twenty-seven experiments were conducted and output Parameters i.e. results are mentioned in Table 4 below.

TABLE 3. Selection of input parameters with levels

| Sr. No. | Factor                        | Levels | Level 1 | Level 2 | Level 3 |
|---------|-------------------------------|--------|---------|---------|---------|
| 1       | Compression Ratio             | 3      | 13      | 15      | 17      |
| 2       | Load (kg)                     | 3      | 4       | 8       | 12      |
| 3       | Biodiesel Blend (%)           | 3      | B20     | B40     | B60     |

TABLE 4. Taguchi L9 orthogonal array

| Experiment No. | Compression Ratio (CR) | Load (kg) | Biodiesel Blend (%) | Brake Power (BP, kW) | Brake Thermal Efficiency (BTE, %) | Specific Fuel Consumption (SFC, kg/kWh) |
|----------------|------------------------|-----------|---------------------|----------------------|----------------------------------|----------------------------------------|
| 1              | 13                      | 4         | B20                 | 1.14                 | 16.34                            | 0.52                                   |
| 2              | 13                      | 4         | B40                 | 1.15                 | 16.43                            | 0.52                                   |
| 3              | 13                      | 4         | B60                 | 1.12                 | 17.49                            | 0.49                                   |
| 4              | 13                      | 8         | B20                 | 2.14                 | 24.54                            | 0.35                                   |
| 5              | 13                      | 8         | B40                 | 2.37                 | 24.02                            | 0.36                                   |
| 6              | 13                      | 8         | B60                 | 2.22                 | 20.13                            | 0.43                                   |
| 7              | 13                      | 12        | B20                 | 3.31                 | 25.91                            | 0.33                                   |
| 8              | 13                      | 12        | B40                 | 3.17                 | 26.00                            | 0.33                                   |
| 9              | 13                      | 12        | B60                 | 3.24                 | 27.92                            | 0.31                                   |
| 10             | 15                      | 4         | B20                 | 1.11                 | 14.69                            | 0.58                                   |
| 11             | 15                      | 4         | B40                 | 0.99                 | 15.53                            | 0.55                                   |
| 12             | 15                      | 4         | B60                 | 1.18                 | 18.42                            | 0.47                                   |
| 13             | 15                      | 8         | B20                 | 2.21                 | 23.82                            | 0.36                                   |
| 14             | 15                      | 8         | B40                 | 2.39                 | 24.16                            | 0.35                                   |
| 15             | 15                      | 8         | B60                 | 2.20                 | 23.70                            | 0.36                                   |
| 16             | 15                      | 12        | B20                 | 3.23                 | 27.84                            | 0.31                                   |
| 17             | 15                      | 12        | B40                 | 3.34                 | 26.09                            | 0.33                                   |
| 18             | 15                      | 12        | B60                 | 3.38                 | 26.43                            | 0.32                                   |
| 19             | 15                      | 12        | B40                 | 1.13                 | 17.71                            | 0.48                                   |
| 20             | 15                      | 12        | B60                 | 1.05                 | 16.50                            | 0.52                                   |
| 21             | 17                      | 4         | B20                 | 1.17                 | 30.56                            | 0.28                                   |
| 22             | 17                      | 4         | B40                 | 2.21                 | 25.31                            | 0.34                                   |
| 23             | 17                      | 4         | B60                 | 2.26                 | 24.34                            | 0.35                                   |
| 24             | 17                      | 8         | B20                 | 2.24                 | 96.45                            | 0.09                                   |
| 25             | 17                      | 8         | B40                 | 3.18                 | 30.45                            | 0.28                                   |

Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is a statistical method used to identify the differences among group means in sample experiments, it is based on the law of total variance where observed variance in particular variable is divided into components attributes to various sources of variation [28].

Signal to noise ratio (S/N Ratio)

Taguchi method is used in present work to minimize the variations in the performance due to presence of undesirable factors called noise. Signal to noise ratio is high which means there is minimum effects of the noise of experiments. There are three different types of S/N ratio such as larger the better,
smaller the better and nominal the best. Selection of S/N ratio depends on the objective of research work [29].

RESULTS AND DISCUSSION

The main objective of present work is to optimize the output parameters i.e. Brake power (BP), Brake Thermal Efficiency (BTE) and Specific Fuel Consumption (SFC). Brake power and Brake Thermal Efficiency of the VCR engine should be high as possible so ‘Larger is better’ S/N ratio is considered and Specific Fuel Consumption (SFC) should be less so “smaller is better” S/N ratio is considered.

Figure 2 shows the main effect plot for SN ratios of Brake Power; Maximum Mean value for Brake power is 6.1106 at 13 CR, 10.2774 at 12kg load and 6.1800 at B60 blend. Minimum Mean value for Brake power is 6.0505 at 17 CR, 0.9380 at 4kg load and 6.0132 at B20 blend. Delta value is the difference between maximum and minimum value of Mean [30].

Table 5 shows the response table for Brake Power, here S/N ratio is larger the better. Maximum value of Delta is for load i.e. 9.3393 having rank 1 and minimum i.e. 0.0601 for Compression ratio having rank 3, it means Load is having maximum and compression ratio is having minimum effect of on Brake Power [31] this result can be confirmed with S/N ratio and ANOVA [32, 33].

From Tables 5 and 6, it is clear that load affects at about 99.42 % on Brake Power of VCR Engine. Figure 3 shows the main effect plot for SN ratios of Brake Thermal Efficiency; Maximum Mean value for Brake Thermal Efficiency is 29.47 at 17 CR, 29.10 at 12kg load and 29.17 at B60 blend. Minimum Mean value for Brake Thermal Efficiency is 26.71 at 13 CR, 24.99 at 4kg load and 26.79 at B40 blend. Delta value is obtained by subtracting minimum value of Mean from maximum value of mean.

Table 7 shows the response table for Brake Thermal Efficiency, here S/N ratio is larger the better. Maximum value of Delta is for load i.e. 4.11 having rank 1 and minimum i.e. 2.38 for Blend having rank 3, it means Load is having maximum and blend is having minimum effect of on Brake Thermal Efficiency this result can be confirmed with S/N ratio and ANOVA. From Tables 7 and 8, though error in this experiment is 57.87% but also load affects at about 30.97% on Brake Thermal Efficiency of VCR Engine.
Figure 4 shows the main effect plot for SN ratios of Specific Fuel Consumption; Maximum Mean value for Brake Thermal Efficiency is 10.843 at 17 CR, 10.467 at 12kg load and 10.506 at B60 blend. Minimum Mean value for Specific Fuel Consumption is 8.035 at 13 CR, 6.305 at 4kg load and 8.153 at B40 blend.

Table 9 shows the response table for Specific Fuel Consumption; here S/N ratio is smaller the better. Maximum value of Delta is for load i.e. 4.117 having rank 1 and minimum i.e. 2.353 for Blend having rank 3, it means Load is having maximum and blend is having minimum effect of on Specific Fuel Consumption. This result can be confirmed with S/N ratio and ANOVA. From Tables 9 and 10, error in this experiment is 20.88% and load affects at about 56.27% on Specific Fuel Consumption of VCR Engine.

![Figure 4. Main effect plot for SN ratios of specific fuel consumption](image)

Table 9 shows the response table for Specific Fuel Consumption (smaller the better)

| Level | CR     | Load (Kg) | Blend |
|-------|--------|-----------|-------|
| 1     | 8.035  | 6.350     | 8.334 |
| 2     | 8.116  | 10.177    | 8.153 |
| 3     | 10.843 | 10.467    | 10.506|
| Delta Value | 2.808  | 4.117     | 2.353 |
| Rank  | 2      | 1         | 3     |

Table 10. Analysis of variance for specific fuel consumption

| Source   | DF | Adj SS  | Adj MS  | F-Value | P-Value | Percentage (%) |
|----------|----|---------|---------|---------|---------|----------------|
| CR       | 2  | 0.04565 | 0.022826| 6.71    | 0.006   | 14.02          |
| Load (Kg)| 1  | 0.18316 | 0.091581| 26.94   | 0.000   | 56.27          |
| Blend    | 2  | 0.02867 | 0.014337| 4.22    | 0.030   | 8.80           |
| Error    | 20 | 0.06799 | 0.003399| 0.00    | 0.00    | 20.88          |
| Total    | 26 | 0.32547 |         |         |         | 100            |

CONCLUSION

An experimental evaluation and Taguchi based optimization is carried out on Single Cylinder VCR Diesel Engine with variable compression ratios and load using Canola based biodiesel. Taguchi method is used to find out effect of input parameters which are directly affecting the output. Contribution of individual parameter on output parameters such as Brake Power, Specific Fuel Consumption and Brake Thermal Efficiency is evaluated.

Results of Taguchi based optimization show that load is the most critical factor which directly affects the engine performance i.e. Increase in load decrease the value of Brake Power, Brake Thermal Efficiency and increases the Specific Fuel Consumption and vice versa. Contribution of Load on variation of Brake Power, Brake Thermal Efficiency and Specific Fuel Consumption is 99.42 %, 30.97% and 56.27%, respectively.

Further it is observed that Biodiesel is not affecting much on output parameters and its contribution is very less like 0.420%, 11.71% and 8.80% on Brake Power, Brake Thermal Efficiency and Specific Fuel Consumption, respectively. As percentage contribution is less than 10% it means Biodiesel can be used as fuel to conventional Diesel fuel.

It is observed that VCR Engine can perform very well when compression ratio is 17, load on the engine is 8kg and Biodiesel at B60. From the results obtained from experimentation and optimization Highest Brake power i.e. 3.38 kW can be produced at B60, and Highest Brake Thermal Efficiency and Lowest Specific Consumption can be obtained Biodiesel at B60. If manufacturing costs get reduced and availability of Biodiesel is made easily then it can be used as alternative fuel for Diesel Engine.

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چکیده
توسعه سیستم‌های جایگزین نانو به اتروی زیرا دراز. به‌بسیاری جا و گزینه استفاده از این نوع انتهایی از سوخت‌های سیلی‌مانند نفت و دیزل برای جا و گزینه و مسیر انتقال می‌شود. میزان پیش‌بینی مصرف این سوخت‌های طبیعی که در دسترس است مربوط به کاهش و خراب شدن محیط ام‌می‌تواند برای حالت اصلی از نظر اولیه کاهش و اصلاح این موضوع باعث بهبود درست‌ساخته‌های قابل درک بزرگترین راه‌های مصرف این سوخت‌های طبیعی می‌باشد. بنابراین بررسی و تحلیلیسی‌های مصرف سوخت‌های طبیعی می‌باشد.


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Persian Abstract