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Technical Note

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

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A B S T R A C T

Rapid development of the global economy demands huge amount of Energy. Transportation sector contributes major part of economy development. Fossil fuels like Petrol and Diesel are used for transportation and heavy duty vehicles. Higher rate of consumption of these naturally available fuels leads to its depletion and deterioration of environment. To solve such issue many researchers are interested in identifying and using alternative fuels for internal combustion engines. Biodiesel is renewable fuel and can be used as alternative fuel for Diesel engines. In present work Canola oil based Biodiesel (COB) is blended in Diesel with different concentration like B20, B40 and B60. Engine input variables like compression ratio (13:1, 15:1, 17:1) and load (4, 8,12kg) are considered to optimize the results. The Performance of Variable Compression Ratio (VCR) Diesel Engine is evaluated using Taguchi method. Analysis of variance is conducted to recognise the significance of input variables on Brake Thermal Efficiency, Brake power Specific Fuel Consumption. Results of optimization showed that load is the most crucial factor which affects the engine performance i.e. Increase in load decrease the Brake Thermal Efficiency, Brake Power and increases the Specific Fuel Consumption.

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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. Bio fuels 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:15ºC	kg/m^3	885.0	860-900	IS:1448(P:16/32)
2	Kinematic Viscosity at 40ºC	Cst	8.00	2.5-8.0	IS:1448(P:25)
3	Flash Point(PMCC)	ºC	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 o 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
13	15	4	B60	1.18	18.42	0.47
14	15	8	B20	2.21	23.82	0.36
15	15	8	B40	2.39	24.16	0.35
17	15	8	B60	2.20	23.70	0.36
18	15	12	B20	3.23	27.84	0.31
19	15	12	B40	3.34	26.09	0.33
20	15	12	B60	3.38	26.43	0.32
21	17	4	B20	1.13	17.71	0.48
22	17	4	B40	1.05	16.50	0.52
23	17	4	B60	1.17	30.56	0.28
24	17	8	B20	2.21	25.31	0.34
25	17	8	B40	2.26	24.34	0.35
26	17	8	B60	2.24	96.45	0.09
27	17	12	B20	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.

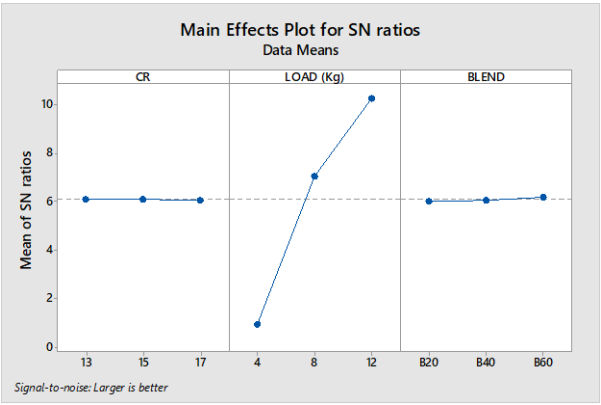

Figure 2. Main effect plot for SN ratios of brake power

TABLE 5. Response table for brake power (larger the better)

Level	CR	Load (kg)	Blend
1	6.1106	0.9380	6.0132
2	6.0887	7.0344	6.0566
3	6.0505	10.2774	6.1800
Delta Value	0.0601	9.3393	0.16667
Rank	3	1	2

TABLE 6. Analysis of variance for brake power

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage (%)
CR	2	0.0036	0.0018	0.33	0.721	0.017
Load (Kg)	2	20.8217	10.4108	1912.19	0.000	99.42
Blend	2	0.0088	0.0044	0.81	0.459	0.0420
Error	20	0.1089	0.0054			0.52
Total	26	20.9430				100

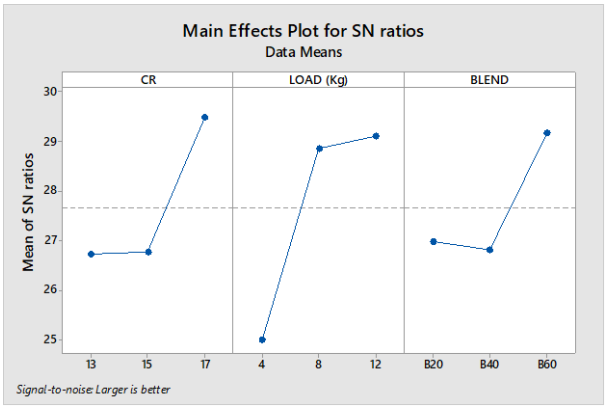

Figure 3. Main effect plot for SN ratios of brake thermal efficiency

TABLE 7. Response table for brake thermal efficiency (larger the better)

Level	CR	Load (Kg)	Blend
1	26.71	24.99	26.98
2	26.76	28.85	26.79
3	29.47	29.10	29.17
Delta Value	2.76	4.11	2.38
Rank	2	1	3

TABLE 8. Analysis of variance for brake thermal efficiency

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage (%)
CR	2	895.5	447.8	2.59	0.100	14.94
Load (Kg)	2	923.0	461.5	2.67	0.094	30.97
Blend	2	700.6	350.3	2.02	0.158	11.71
Error	20	3461.0	173.1	-	-	57.87
Total	26	5980.1	-	-	-	100

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.

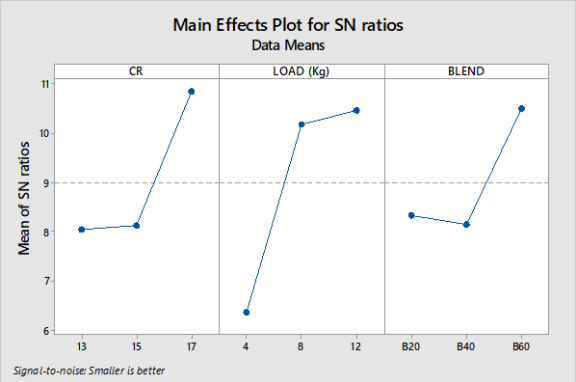

Figure 4. Main effect plot for SN ratios of specific fuel consumption

TABLE 9. 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)	2	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			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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Persian Abstract

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چکیده

توسعه سریع اقتصاد جهانی نیاز به انرژی زیادی دارد. بخش حمل و نقل بخش عمده‌ای از توسعه اقتصاد را به عهده دارد. از سوخت‌های فسیلی مانند نفت و دیزل برای حمل و نقل و وسایل نقلیه سنگین استفاده می‌شود. میزان بیشتر مصرف این سوخت‌های طبیعی که در دسترس است منجر به کاهش و خراب شدن محیط آن می‌شود. برای حل این مسئله بسیاری از محققان علاقه‌مند به شناسایی و استفاده از سوخت‌های جایگزین برای موتورهای احتراق داخلی هستند. بیودیزل سوخت تجدیدپذیر است و می‌تواند به عنوان سوخت جایگزین برای موتورهای دیزل مورد استفاده قرار گیرد. در کار حاضر بیودیزل مبتنی بر روغن کلزا (COB) در دیزل با غلظت‌های مختلف مانند B20، B40 و B60 مخلوط می‌شود. متغیرهای ورودی موتور مانند نسبت فشرده‌سازی (۱۳: ۱، ۱۵: ۱ و ۱۷: ۱) و بار (۴، ۸ و ۱۲ کیلوگرم) برای بهینه‌سازی نتایج در نظر گرفته شده‌اند. عملکرد دیزل موتور نسبت فشرده‌سازی متغیر (VCR) با استفاده از روش تاگوچی ارزیابی می‌شود. تجزیه و تحلیل واریانس برای تشخیص اهمیت متغیرهای ورودی بر راندمان حرارتی ترمز، مصرف سوخت ویژه ترمز انجام می‌شود. نتایج بهینه‌سازی نشان داد که بار مهمترین عاملی است که بر عملکرد موتور تأثیر می‌گذارد. افزایش بار باعث کاهش راندمان حرارتی ترمز، قدرت ترمز و افزایش مصرف سوخت خاص می‌شود.