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Experimental Investigation of Engine Parameters Influence on Performance and Emissions of Biodiesel Fuelled CI Engine

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Abstract— **In this experimental investigation of the optimum combination feasibility of compression ratio (CR) and blend percentage were analyzed at constant speed by using Taguchi method. In this research performance parameter considered was Brake Thermal Efficiency (BTE), as maximum efficiency of engine is desirable. Carbon dioxide (CO_2) and Nitrogen oxides were considered as emission output responses, as maximum CO_2 emission is indication of reduction in HC and CO. The experimentation was carried out in single cylinder 4 stroke VCR CI engine at 16:1, 17:1 and 18:1 CR with 10, 20 and 30 percentage of Jojoba oil biodiesel-diesel blends at 1550 rpm speed. The contributions of each parameter and output response were evaluated by ANOVA and 3D surface plot. The investigational results reveals that at 18 CR and B10 BTE of engine was maximum where CR was the more influencing parameter, due better combustion of fuel at higher CR. Blend type was the more influencing factor for the higher CO_2 discharge, because higher oxygen molecules in biodiesel. The influence of CR was more in production of NOx. At lower CR NOx emissions were found minimum.**

Keywords—biodiesel; performance; emission; blend; compression ratio.

I. INTRODUCTION

Energy is a fundamental and essential parameter for economic and social progress of any nation. Increased utilization of remnant fuels and fear due to ecological pollution due to fossil fuels are the main issues which promote the researchers of all over the globe to find optional or substitutive renewable energy source. Various statistical studies are also observed in the literature related with performance and emissions evaluation using biodiesel, biodiesel- pure diesel blends and pure diesel. They are optimization studies using different techniques to optimize the engine parameters using experimental data to interpolate the performance and emission predictions. Several techniques are existing for optimization. The optimization studies are as follows:

The experimentation for engine characteristics fuelled Karanja oil methyl ester mixtures with pure diesel on a variable compression ratio DI CI diesel engine. The optimal process output found through a limited number of experiment runs by using of Taguchi method and with grey relational. Using signal-to-noise ratio and grey relational grade as a performance parameter, an optimum combination of input variables was predicted to achieve most suitable response. It was observed that 50-50 % mixture of biodiesel-diesel was most appropriate for diesel engine without considerably disturbing the engine characteristics [1]. In the investigational study of optimum performance an attempt was made to discover the optimum fraction possibility of four parameters namely low concentration thumba biodiesel diesel mixtures, injection pressure, compression ratio, and angle of injection on single cylinder adjustable compression ratio CI engine applying Taguchi process analysis. A L9 orthogonal array was applied to accumulate data for different engine operations and exhaust related response, at zero, partial and maximum engine loading situation. As the process is multi-response performance behavior, so the grey relational estimations which uses grey relational grade for performance index is specially used to calculate the optimal arrangement of engine performance variables. The results revealed that combining of parameters and their intensity comprising of a mixture including of 30% thumba biodiesel (B30), a CR of 14, with injection pressure of 250 bar and the injection angle of 20º gives highest multi-performance of CI engine combined with least multiple-emission concentration of the engine[2].

Researchers did improvement of the performance of biodiesel–methanol blended VCR engine by optimizing the engine input variables. The input parameters considered for optimization of the engine were load, fuel blend and compression ratio whereas performance parameters such as BTE, BSFC and emission parameters such as CO, HC, Nitric oxides (NOx) and smoke were considered as responses. Investigation was carried out according to design of experiments of the response surface methodology. Optimization of engine operational parameters was done using statistical approach. The results showed that the engine has highest performance and lower exhaust gas at, 9.03 kg of load, 5% fuel blend and at 18 compression ratio. At this suitable working condition the engine responses such as BTE, BSFC, CO, HC, NOx and smoke are found to be 31.95%, 0.37 kg/kW h, 0.036%, 5 ppm, 531.23 ppm and 15.35% respectively [3]. The signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) were used to detect the appropriate levels and to evaluate the influence of the working environment on emission and performance of engine. The variables and their levels were EGR proportion of 0, 10, 20, 30%, steam proportion of 0, 10, 20 and 30% and speeds at 1200, 1600, 2000 and 2400 rpm %. Validatory experiments with optimum levels of engine variables were performed in order to demonstrate the efficiency of the Taguchi optimization method. However, EGR and steam ratios were found significant on emission variables; impact levels for these variables have been found lower for effective torque. Thus it was proved that the Taguchi method is an appropriate way to investigate the optimum performance and emissions of diesel engines [4].

Statistical method for thermodynamic analysis of Jatropha biodiesel fuelled engine with Taguchi's optimization approach to evaluate the optimal engine design and working parameters. A model depends on two-zone Weibe's heat release function was used to simulate the engine performance with Jatropha biodiesel. Amongst the all important design and operating variables 10 significant variables were chosen assuming connections among the pair of variables. Applying linear graph and Taguchi method an L16 orthogonal array has been generated to perform the engine test trials. In order to increase the performance of engine the signal to noise ratio (SNR) related to higher-the-better (HTB) characteristics has been selected. The methodology predicted that Weibe's heat release constants, combustion zone duration and compression ratio were the most significant variables which affects the engine performance relative to other variables. The scallop waste shell was used for preparation of Biodiesel from Palm Oil and optimized with taguchi process. The optimization of investigational elements, such as reaction temperature, reaction time, methanol/oil molar relation and catalyst use, on the transesterification for the creation of biodiesel has been considered. A Taguchi L9 (34) orthogonal array were used to assess the parameters affecting the yield of palm oil to fatty acid methyl ester (FAME). The scallop waste shell was calcined at 1,000 ^{0}C for 4 hrs and catalyst characterizations were carried out by different surface region measurements. In the optimal reaction situation of 10 wt. % of catalyst, 9:1 methanol/oil molar proportion and at a temperature of 65 0C, the FAME yield was 95.44% and it was attained in 3 hrs. It was observed that the scallop waste shell catalyst indicates high catalytic action and eco-friendly properties, having the capability to be utilized in biodiesel preparation process as base catalyst [5, 6].

Investigators studied combustion characteristics of pongamia biodiesel in DI compression ignition engine. The performance, emissions and combustion characteristics of biodiesel derived from pongamia oil and blends compared with conventional diesel fuels. The results revealed that diesel engines can function well with pongamia oil methyl esters and blends thereof without modifying the engine. As the proportion of biodiesel in the biodiesel mixture increases, the SFC increases due to the lower calorific value of the biodiesel. Compared to diesel fuel, it has also been observed that the CO, HC and smoke emissions of all biodiesel blends are drastically reduced. However, NOx emissions of biodiesel are slightly higher than petroleum diesel. According to the combustion analysis, biodiesel added to the conventional diesel fuel shortened the delay time of the premixed combustion and decreased the heat release rate. Thus, the results show that pongamia oil methyl ester can be used as an alternative to diesel engine fuel and environmentally friendly. An experimental was conducted to study on the influence of CR and IP in diesel engines using Jatropha methyl ester. The research aimed to find biodiesel compatibility with respect to the standard design parameters of diesel engines. The results revealed that the CR increase up to 18.5 improves the performance of biodiesel. Three injection pressures of 150, 200 and 250 bar were considered during the test. The BSFC was the lowest at 200 bars at 50% load. This may be due to a better atomization and a slight delay in fuel entry. As fewer losses are encountered at higher loads, BTE increases by about 8.9% with load. In CR of 18, the BTE increases by 5.5% due to good combustion and higher lubricity. Higher compression ratios generally ensure better combustion due to the appropriate atomization available for adequate fuel-air mixing and higher surface area. Emissions from engines such as particulate hydrocarbons, NOx, EGT, smoke opacity are lower than diesel, CO and CO2 emissions are slightly increasing. Due to the high exhaust gas temperature, NOx emissions slightly increased at 250 bar or more. All comparisons are done on biodiesel against diesel baseline data [7, 8].

A statistical approach for preparation of biodiesel from babassu Oil was explained by the researchers. The methyl esters from babassu oil and methanol by adding potassium hydroxide (KOH) as catalyst has been obtained and optimized by using the response surface methodology and factorial design of experiments. The various parameters influencing the alkaline methanolysis of the babassu oil were investigated. Temperature of reaction was found to have the highest significant effect on yield. As per to this study and from an financial point of view, the better conditions for whole reactions are catalyst fraction of 0.95% and an working temperature of 45°C operating with 6:1 methanol/oil molar proportion. With these circumstances the maximum yield obtained was 99.85%. The biodiesel created from babassu oil includes a high level of saturated fatty acids, 91%, majorly composed of lauric acid (51.8%) and myristic fatty acid (22.2%) making it mainly stable regarding oxidation and ensuing in better cold flow properties. The babassu oil biodiesel (BO-BD) could be transformed in a mostly promising replacement for conservative fuel probably because of the better low temperature properties, higher oxidative stability shown and fulfilling the Biodiesel Standard EN 14214. These significant properties can make BO-BD of a huge interesting fuel [9, 10].

II. EXPERIMENTATION

A. *Materails and Methods*

The biodiesel required for engine was prepared from jojoba oil. The transesterification process was used for obtaining the biodiesel. After formation of final biodiesel B10, B20 and B30 biodiesel-diesel blends were prepared with 10%, 20% and 30% of biodiesel in pure diesel. The calorific values of blend were found 42.25Mj/kg, 42.09Mj/kg, 41.89 Mj/kg and 42.5Mj/kg for B10, B20, B30 and pure diesel respectively.

B. *Perfomance and EmissionTesting in CI Engine :*

Performance tests were conducted on stationary single cylinder, VCR DI diesel engine, using jojoba oil biodiesel and its blends JJB10, JJB20 and JJB30 with diesel at constant load of 9 kg. Petro diesel is used before the biodiesel blends for verifying the engine performances and emissions.

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Fig. 1 Engine test setup

The engine used for the testing of the biodiesel has the following specifications

TABLE I ENGINE SPECIFICATIONS

Manufacturer	Kirloskar
Model	TV1
No. of strokes	Four strokes
Cylinder Diameter	87.5 mm
Fuel system	Direct injection
Stroke Length	110 mm
Connecting Rod Length	234 mm
Compression Ratio	12 to 18:1
Maximum power	5.2 KW @ 1500 rpm

AVL DITEST Gas 1000 BL type 5 gas analyzer was used for emission measurement. The analyzer measured the exhaust gases emission (in parts per million and % vol) to determine both combustion efficiency and the amount of pollutants in the exhaust. CO, HC, O_2, CO_2 and NOx were measured as major emission parameters. The display Gas Analyzer used for testing is shown in Fig. 2

Fig. 2 Exhaust gas Analyzer display

III. RESULT AND DISCUSSION

The various performance and emission characteristics of engine were measured by changing the compression ratio and blend percentage. For investigating the optimum parameter Brake Thermal Efficiency (BTE), Carbon dioxide (CO_2) and Nitrogen oxides (NOx) were considered. Fig. 3 shows the input and output for a CI engine at Ideal condition.

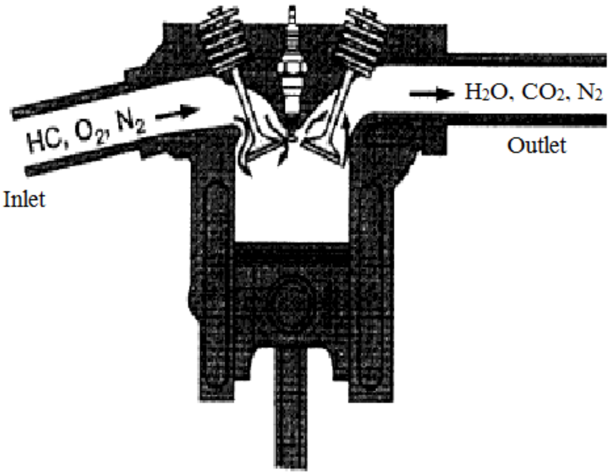

Fig. 3 Ideal combustion of fuel

As under the perfectly operating engine conditions with ideal combustion the hydrocarbon(HC) reacts with oxygen forming water vapor and CO_2, so higher CO_2 emission is a indication of better combustion. The Nitrogen (N_2) passes through the engine without affecting the combustion process, so minimum NOx percentage is desirable.

For investigation of optimum performance and emission characteristics of CI engine two engine input parameters CR and Blend type were selected. Three level of each parameter were considered as shown in Table II.

TABLE II CI ENGINE INPUT PARAMETERS AND THEIR LEVELS

Symbols	Engine Input Parameters	Levels		
		1	2	3
A	Compression Ratio	16	17	18
B	Blend Type	B10	B20	B30

The engine speed was kept constant at 1550 rpm for all experiments. As the BTE is most important factor of engine performance, it was chosen to showing the performance response. CO_2 and NOx considered as emission response in which higher CO_2 and lower NOx were desirable. The engine outputs for different Taguchi designed input combinations are shown in Table III

TABLE III TABULATION OF DATA FOR TAGUCHI METHOD WITH RESPONSE

CR	BLEND	BTE (%)	CO2 (%)	NOx(pap)
16	B10	28.82	2.61	205
16	B20	27.83	3.41	213
16	B30	26.70	3.62	210
17	B10	28.98	2.81	226
17	B20	27.92	3.43	224
17	B30	27.37	3.53	238
18	B10	31.39	2.93	243
18	B20	27.92	3.48	253
18	B30	28.96	4.14	272

A. Influence of CR and Blend on BTE:

As the conventional technique could not detect the variability of the results signal to-noise ratio concept was applied to analyze the output and input correlations. As the goal of the experiment was to evaluate the highest BTE, for the highest possible result, the higher-the-better (HB) condition was applied.

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The S/N ratio with higher is best is presented as,

$$\eta_{ij} = -10 \log \left\{ \frac{1}{n} \sum_{j=0}^{n} \frac{1}{y_{ij}^2}) \right\}$$

Where, y_{ij} is the i[th] output of j[th] experimentation, n is total number of tests

The investigations of the output were done by using Minitab software. The graphical presentation of *S/N* ratio for two parameters, CR and blends is shown in the main effect plot Fig.4. If the plot line for a parameter have minimum slope then that parameter has less influence on response. Whereas, a factor for which the plot line has maximum slope will have the most influence on output. From the plot, it had been noted that type of blend has the most influence on BTE compared to influence of CR. It indicates that at 18 CR and B10 blend, there will be maximum output.

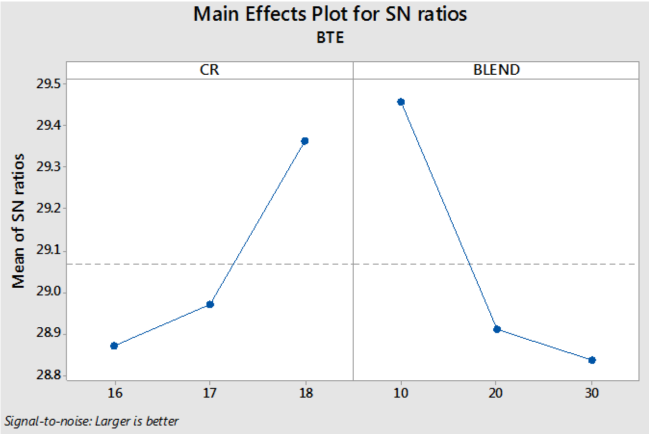

Fig. 4 Main effect plot of SN ratio for BTE

The responses achieved after executing the experiments with different input combinations revealed the contribution of each parameter. Analysis of Variance (ANOVA) obtained by Taguchi method is shown in Table IV. The most important factor enfluencing the BTE was identified by evaluating the contribution. From the table it was noted that blend type was the most important factor influencing the BTE having 52.75% contribution .

TABLE IV ANALYSIS OF VARIANCE FOR BTE

Source	DF	Seq SS	Adj SS	Adj MS	F
CR	2	4.561	4.561	2.2807	3.99
BLEND	2	7.647	7.647	3.8236	6.69
Residual Error	4	2.285	2.285	0.5713	
Total	8	14.494			

BTE 3D surface plot against blend and compression ratio is as shown in Fig. 5 to describe the influence of jojoba biodiesel blend and CR on it. From the figure it was noted that BTE of the engine seems to be decreasing with the increase in biodiesel content. This may be because of higher in oxygen content of the biodiesel. The BTE increases with increase in CR, as higher CR gives more pressures and temperatures inside the cylinder. Higher temperature and pressures are the desired phenomena in BTE perspective.

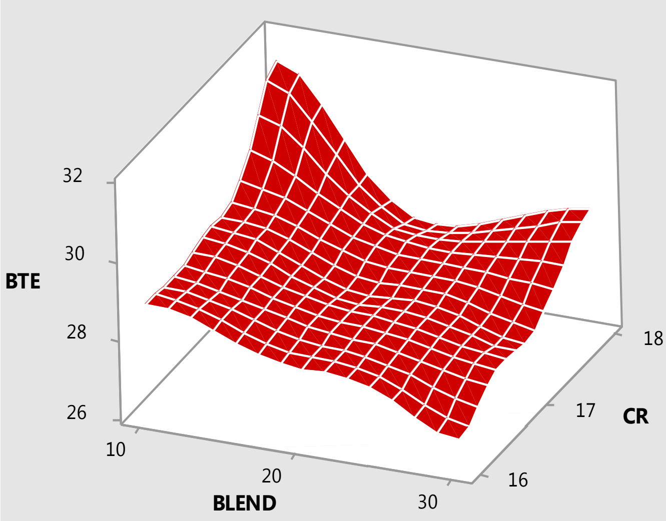

Fig. 5 3D Suraface plot for BTE vs. CR & Blend

The maximum value of BTE was found to be 31.39% at 18 CR and B10. The least value 26.70% was found at 16 CR and B30.

B. *Influence of CR and Blend on CO_2*

The higher CO_2 is indication of better fuel combustion with lower HC and CO, therefore from the engine exhaust higher CO_2 is desirable. To investigate the influence of CR and blend percentage on CO_2 mean effect plot for SN ratio as shown in Fig 6 was obtained by considering the condition higher is better. The mean effect plot shows that percentage of CO_2 was maximum at 18CR and B30. This due to better combustion of fuel at higher CR and more oxygen content fuel and higher blend percentage.

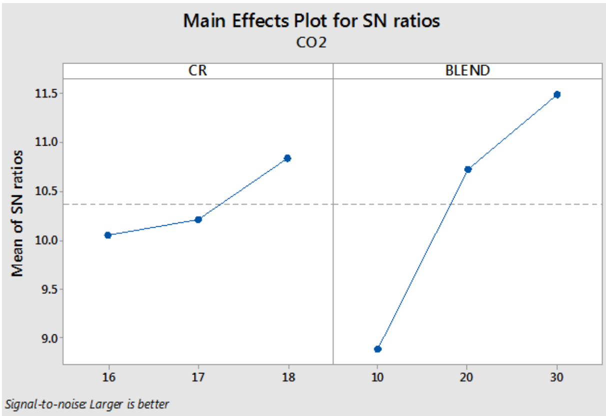

Fig. 6 Main effect plot of SN ratio for CO_2

Analysis of Variance obtained by Taguchi method is presented in Table V. From the ANOVA it was observed that blend percentage was the more important parameter affecting the CO_2 quantity in exhaust gas. It was noted that contribution of blend type was 84.63%.

TABLE V ANALYSIS OF VARIANCE FOR CO2

Source	DF	Seq SS	Adj SS	Adj MS	F
CR	2	0.1615	0.1615	0.08074	2.93
BLEND	2	1.4962	1.4962	0.74808	27.14
Residual Error	4	0.11.2	0.1102	0.02756	
Total	8	1.7679			

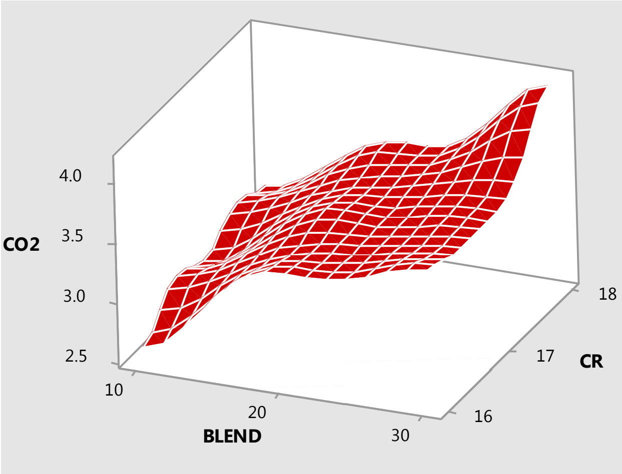

Fig. 7 3D Suraface plot for CO_2 vs. CR & Blend

The 3D surface plots for CO_2 shows the significance of CR and blend type together with all input factors. It shows that for maximum CO_2 emissions in exhaust it's better to run engine at 18 CR because higher CR gives better combustion. It was observed that CO_2 is higher for B30; this is due to more oxygen content in higher blends. The maximum value of CO_2 was found to be 4.14 % at 18CR and B30. The least value of CO_2 is 2.61 at 16CR and B10.

C. Influence of CR and Blend on NOx

NOx emissions are depends on the temperature of combustion. As NOx are harmful pollutants its existence in exhaust is undesirable. There the target of the experiment was to produce the least possible NOx, for the lowest possible result, the lower-the-better condition of SN ratio was applied.

The S/N ratio with lower is best is presented as,

$$\eta_{ij} = -10 \log \left\{ \frac{1}{n} \sum_{j=0}^{n} y_{ij}^2 \right\}$$

Where, y_{ij} is the ith output of j^{th} experimentation, n is total number of tests.

The main effect plot for SN ratio shows that CR has most significant influence on NOx than blend percentage.

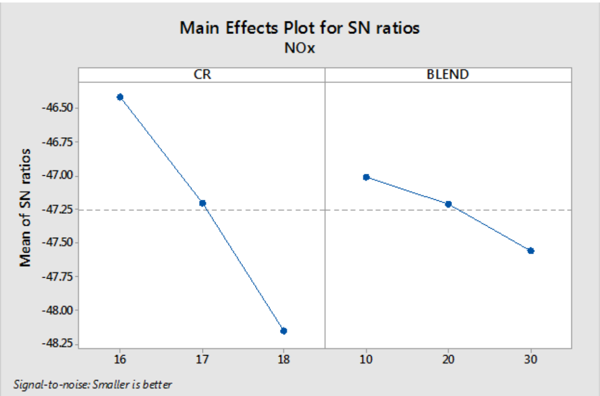

Fig. 8 Main effect plot of SN ratio for NOx

The ANOVA model obtained NOx as response for CR and blend type is presented in Table VI. It was observed that, cotribution of CR on NOx production was 84.98%. It clearly indicates that at lower CR the NOx emissions are lower and it increases with increase in CR.

TABLE VI ANALYSIS OF VARIANCE FOR NOX

Source	DF	Seq SS	Adj SS	Adj MS	F
CR	2	3288.9	3288.9	1644.4	30.20
BLEND	2	363.6	363.6	181.78	3.34
Residual Error	4	217.8	217.8	54.44	
Total	8	3870.2			

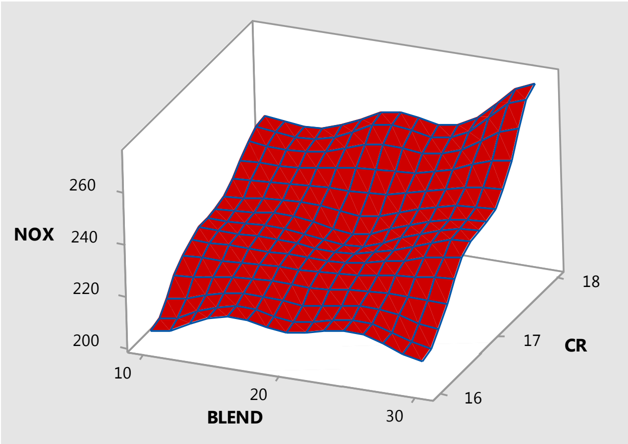

Fig. 9 3D Suraface plot for NOx vs. CR & Blend

Fig. 9 indicates the change of NOx emissions against CR and blend percentage. It was observed that the NOx emissions were increased with increase in percentage of biodiesel in blend. It was noted that highest NOx found to be 272 ppm at 18CR and B30; this is due to the higher temperature and pressure inside the combustion chamber. At 16 CR and B10 the NOx observed were minimum with 205 ppm. In CI engines NOx emissions in exhaust are higher due to the higher CR.

CONCLUSIONS

From this experimental investigation points were concluded:

- The CR is most significant than blend percentage for higher BTE. The BTE is highest at the higher CR and least at the low CR. This is because of better combustion at higher CR.
- Blend percentage is the more significant parameter than CR for the higher CO_2 emission. This is due to higher oxygen content in higher biodiesel blends.
- For controlling the NOx emissions CR is more significant than blend percentage.

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