JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Optimization of Performance and Emission Characteristics of Jojoba Biodiesel on CRDI Diesel Engine through Response Surface Methodology

Yash Raj[1], Abhishek Bhandari[2]
Research Scholar[1], Professor & Head[2]
Department of Mechanical Engineering,
NRI Institute of Research and Technology, Bhopal
[1]myashraj28@gmail.com, [2]abhishek.bhandari08@gmail.com

Abstract : Human beings are heavily dependent on crude oil for their various need of survival on this planet but the way humans use crude oil make scientists to think deeply about renewable sources. One of the substitutes for the fossil fuel is a biodiesel. Several research are done on different biodiesels which concludes that biodiesel can be surely used as an alternative or it can be used to decrease the use of specially diesel fuel. In this paper, a single-cylinder, water cooled CRDI diesel engine was run with jojoba biodiesel by changing input parameters i.e., blend% (10, 15 ,20 ,25, and 30), Load (0, 3, 6, 9, and 12kg), compression ratio (16, 17, 18, 19, and 20) and injection pressure (190, 210, 230, 250, and 270 bar) to maximize the performance parameters i.e., brake thermal efficiency (BTE) and Exhaust gas temperature(EGT) and minimize emission i.e., CO and NOx are analysed with the help of Response Surface Methodology technique. It uses MINITAB20 to conclude the results and graphs. The result showed that there is significant decrease in all emission variables except marginal increase in NOx emission. The results reveal that overall good performance of the engine with BTE was maximum (24.5%) at blend 25%, CR 19, load 9 kg and IP 210. EGT was found to be minimum (0.11%vol) at blend30%, CR 18, load 6 kg and IP 230 bar. The optimum value of the output variable which is described by RSM is at blend 10.2020%, IP 190 bar, CR 20, Load 2.7879 kg and values are NOx 224.2844 ppm, , CO 0.1105 %vol and EGT 190.6031°C.

IndexTerms – Biodiesel, jojoba, Injection pressure, Compression ratio, Response surface methodology.

I. INTRODUCTION

It is hard to imagine human lives without crude oil but the way diesel engine pollutants are harming environment in every aspect is quite alarming. The climate change and increasing health problems due to air pollution generated from the burning of fossil fuels, which are costly as well as scarce. This has led to a rise in the popularity of biofuels or fuels derived from renewable sources like corn or sugarcane. Crude oil is non-renewable; it will be exhausted in few decades. Crude oil plays an important role in deciding a nation's economy as we have been seeing oil prices are increasing rapidly. Conflicts between nations drastically affects the prices of crude oil, sanction imposed by one nation to other on crude oil and many other. Those nation which are heavily dependent on crude oil trying to shift their policy to generate and use renewable energy, as they are renewable and very less harmful effects to environment and ecosystem.

Biodiesel is a type of diesel made from plants oil or animal fat. It consists of long chain hydrocarbon. Biodiesel is made up of biological ingredients rather than of fossil fuels which makes them the favourable substitute for diesel. Biodiesel is a renewable, non-toxic and biodegradable, similar to this biodiesel contains high cetane number, better ignition performance, high combustion efficiency, contains more oxygen molecule. Besides this mixing of diesel with biodiesel reduces the emission [1]. There are numerous biodiesels already been used in compression ignition engine or we can say that various research work has been already done on different biodiesel such as jatropha, linseed, soyabean oil, mustard oil, rapeseed oil etc. but this research work uses jojoba oil due to its distinct advantages over another biodiesel.

M. Suresh et al. [2] conducted a test using non-edible oils such used frying oil, used cooking oil, madhuca indica, etc. By converting to a VCR engine, we can improve combustion rate and reduce dangerous gas emissions including HC, CO_2, CO, and NOx at all loads. M. Vergel et al. [3] explores a combined fuel approach that adds ethanol as an addition to biodiesel blends to show that it increases fuel consumption since the calorific value of the blend fuel is reduced. With ethanol percentages of 2% and 4%, the BSFC specifically increases by 1.84% and 3.98%, respectively. Geetesh Goga et al. [4] studied on a single cylinder engine using butanol mixes and rice bran biodiesel. With an increase in biodiesel and n-butanol blends, brake-specific fuel consumption increased and is now higher than diesel. For 10% biodiesel blends and 20% biodiesel blends with n-butanol as an addition, brake thermal efficiency was modestly improved. A Saravanan et al. [5] Rapeseed biodiesel and Mahua biodiesel were used in an experiment, and the results showed increased brake-specific fuel consumption for biodiesel, however B20 biodiesel blends' bsfc was close to that of diesel fuel. Qixin Ma et al. [6] performed a test on a diesel engine to determine the emission and performance characteristics of biodiesel-diesel-alcohol mixes. It was discovered that B10P10 emits less THC than other fuels. Abhishek Sharma et al. [7] used the response surface method approach to conduct an experiment on the impact of biogas on the emissions and functionality of diesel engines powered by biodiesel ethanol mixes. The outcome indicates that the optimal values for the variables BTE, HC, CO, and NOx emission are, respectively, 24.29%, 51.6 ppm, 0.0715% volume, and 1080.2 ppm. K.N. Krishnamurthy et al. [8] Utilizing response surface methods, synthesise and optimise Hydnocarpus Wightiana and dairy waste scum as sources for the manufacture of biodiesel. The results showed that the methanol/oil molar ratios of 7:5:1 and 6:526:1 were the best. Golmohammad Khoobbakht et al. [9] optimised biodiesel and ethanol fuels to reduce diesel engine exhaust emissions while using RSM. They come to the conclusion that adding biodiesel to a binary mixture of ethanol and diesel results in more stable fuel mixes than using just diesel and ethanol alone.

This research work uses jojoba biodiesel and various input parameter i.e., blend%, load condition, injection pressure with compression ratio and four different output parameter is analysed, they are BTE and EGT and two emission parameter is also analysed i.e., CO and NOx. Experiment shows some positive effect in emission parameters. Some output shows slightly negative results. The analysis is done by Response Surface Methodology which effectively optimised many combined input variables into small and unique combination. The unique about this experiment is that it uses a unique combination of various practical input variable with some useful data and its effect on emission shows a good result.

Table 1: Viscosity and density of different blends

Properties	**ASTM Method**	**Diesel**	**Jojoba Oil**	**JB10**	**JB20**	**JB30**
Density (g/cm^3)	D-4051	0.828	0.848	0.826	0.833	0.839
Kinematic Viscosity(mm^2/sec)	D-443	2.985	23.67	5.093	7.134	9.23

II. METHODOLOGY AND EXPERIMENTAL SETUP

2.1 Materials and biodiesel preparation

To extract the water content from the jojoba oil, 100ml from the jar was taken in a beaker and pre-heated to 100-110℃. At the same time, methanol by volume and KOH by weight was taken in a fresh beaker and stirred to form a solution. After pre heating of the oil it was allowed to cool to 60℃. When the preheated jojoba oil came to 60℃, the mixture of KOH and methanol were mixed with jojoba oil and stirring was performed on a magnetic stirrer. The mixture of solution maintained at 60℃ and the process of stirring continued for approximately 30 to 45 minutes. After 30-45 minutes the mixed solution was taken into a separate funnel and mixed stirred solution was poured into it to separate glycerol and biodiesel. The sample was not allowed to touch for 24 hours, through this biodiesel was separated from glycerol. At last, for removal of extra impurities i.e., methanol and KOH were still present, they were removed through water washing. The viscosity of density of different blends is shown in table 1.

2.2 Engine Setup (CRDI Engine)

The experimental test of engine was done on CRDI engine model in the automobile section lab of NRI Institute of research and technology, bhopal. As depicted in figure 1, multiple tests were conducted for diesel and various jojoba biodiesel blends with a variety of other input parameters on a single cylinder, water cooled, and 4 stokes VCR engine at a constant speed of 1500 rpm. The other specifications of engine setup are listed in table 3.2. The performance parameters of engine are calculated in the experimental investigation such as BTE and EGT.

Figure 1 CRDI VCR Engine setup

Table 2: Technical specification of engine setup

Model	Kirloskar
No. of Cylinder	1
No. of Strokes	4
Cylinder Diameter	86.4 mm
Stroke Length	105mm
Compression Ratio	14:1 to 22:1
Power	3.4 kW
Speed	1500 rpm
Connecting Rod Length	230 mm
Dynamometer	Water cooled, eddy current
Dynamometer arm Length	180 mm
Load Indicator	Digital, 0-50 kg, 230 V AC supply
Load Sensor	Load cell, strain gauge type, 0–50 kg range

AVL Exhaust Gas Analyser

The gas analyser measures the emission parameter, including CO and NOx is illustrated in figure 2. In this analyser one end has exhaust gas pipe and other is equipped with gas analyser. The technical specification are as follows:

Table 3: AVL Exhaust gas analyser specification

Type	AVL DIX 650
Operating temperature	5℃…...42℃
Storage temperature	0℃……45℃
Warm up time	Approx.…. 2.5 minutes
Humidity	10…...85%
Dimension	340*250*84 (W*H*D)
Weight	2.4 kg
Interface	USB, Bluetooth 1, RS 232
Certificate	2004/22/EC (MID)

Voltage Supply	Via AVL DI TEST CDS Basic unit 11.25V DC
Power Consumption	Approx. 25 VA

2.3 Response surface methodology

A statistical method called response surface methodology examines the connections between various factors and response variables. RSM applies its strategy using a second-degree polynomial equation. Utilizing RSM, the done experiment can be optimised to maximise the supplied process. RSM includes a number of statistical methods for using the model and developing empirical models. The goal of RSM is to establish a connection between response and the magnitude of the influencing input variables. For the configuration of variables, Response Surface Methodology (RSM) has optimization algorithms. The response is modelled by ANOVA and factorial technique. The Response surface methodology is a set of criteria that decides at what points within the feasible region the experiment should be conducted in such a process that the prediction is most precise.

The dependent variables are independently characterised by RSM and the correlation at each level. A second order model, which can be described as follows, typically expresses this:

$$Y = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=1}^{k} \beta_{ij} x_i x_j + \varepsilon$$

Where

Y = is the dependent variable

$\boldsymbol{x_i}$ = Numerical values of the factor

$\boldsymbol{\beta_o}$ = intercept

$\boldsymbol{\beta_i}$, $\boldsymbol{\beta_{ii}}$ and $\boldsymbol{\beta_{ij}}$ = are the coefficients determined for the linear, pure quadratics and cross products of $\boldsymbol{x_i}$, $\boldsymbol{x_i^2}$ and $\boldsymbol{x_i x_j}$ respectively.

ε = experimental error

Response element in order to establish a relationship between independent factors and response that reveals a connection between response variables and independent variables, Y is studied. The deployment of a central composite rotable design (CCRD) describes relatively reliable prediction. The well-regarded MINITAB 20 programme is used to create an RSM model, which returns the quadratic equation for statistical model analysis [26]. Further the number of experimental points (P) can be find using the given equation:

$$\mathbf{P = 2^n + 2n + n_0}$$
$$\mathbf{= 2^4 + (2*4) + 7}$$
$$\mathbf{= 31}$$

Where

P = number of trials to be run

n = number of variables

$\mathbf{n_o}$ = number of central points

Table 4: The layout of the experimental matrix:

Blend(%)	IP (bar)	CR	Load (kg)	Effic.(%)	BSFC(g/kWh)	EGT©	CO(%Vol)	HC(ppm)	NOx(ppm)	Smoke(HSU)
20	230	18	6	24.1	525	226	0.2	34	348	32
15	210	19	3	24	593	204	0.17	19	250	23
20	230	18	6	24.1	525	226	0.2	34	348	32
20	190	18	6	23.9	530	226	0.21	42	355	36
15	250	17	3	23.5	593	212	0.17	31	300	22
15	250	19	3	24.1	590	202	0.13	19	325	19
25	210	19	9	24.5	506	258	0.15	26	490	34
25	210	17	3	23.4	590	245	0.16	26	260	23
15	250	19	9	24.2	510	256	0.13	45	480	37
15	210	17	9	24.3	501	258	0.15	48	410	47
25	250	17	3	23.7	577	213	0.13	20	290	18
25	250	17	9	24.4	508	251	0.13	37	455	36
20	230	18	12	24.7	495	273	0.19	50	550	57

20	230	18	6	24.1	525		226	0.2	34	348	32
20	230	18	6	24.1	525		226	0.2	34	348	32
15	210	17	3	23.7	590		209	0.15	33	245	28
20	270	18	6	24.9	522		226	0.18	26	460	25
25	210	17	9	24.4	520		255	0.12	45	450	43
15	250	17	9	24.4	506		258	0.13	43	465	42
10	230	18	6	23.9	527		226	0.2	36	360	35
20	230	18	6	24.1	525		226	0.2	34	348	32
30	230	18	6	24.1	537		222	0.11	25	380	25
25	210	19	3	23	545		211	0.14	22	310	19
20	230	18	6	24.1	525		226	0.2	34	348	32
20	230	18	6	24.1	525		226	0.2	34	348	32
25	250	19	3	23.67	589		207	0.12	14	360	15
15	210	19	9	24.2	500		255	0.16	47	410	42
20	230	18	0	24.11	655		181	0.13	10	230	36
25	250	19	9	24.4	504		253	0.18	33	495	36
20	230	20	6	24.34	526		226	0.2	27	390	36
20	230	16	6	24.1	510		226	0.21	49	360	36

III. Result and Discussions

RSM optimizer

The operational parameters of the engine in this experiment are optimised using the RSM optimizer. As with IC engines, it is a tool for multi-objective maximisation. The engine's performance will be increased while emissions are kept to a minimum. The ideal engine configuration was determined in this experiment by the RSM optimizer's optimization of the output variables. Blend%, load, CR, and injection pressure serve as the input configuration, and the optimal output variables BTE, EGT, CO and NOx may be derived after that. The RSM optimisation result is with desirability of 0.7882. The optimum value of the output variable which is described by RSM is at blend 10.2020%, IP 190 bar, CR 20, Load 2.7879 kg and values are NOx 224.2844 ppm, HC 16.0299 ppm, CO 0.1105 %vol, EGT 190.6031°C, and BSFC 598.955 g/kWh.

Performance analysis

Impact on brake thermal efficiency

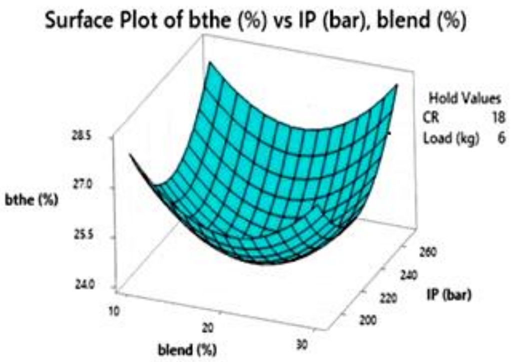

Figure 3.1 Surface plot of bte vs blend & IP

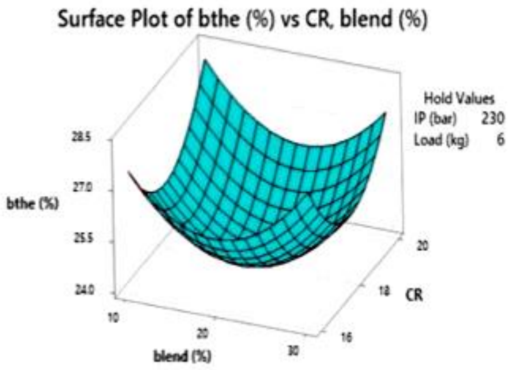

Figure 3.2 Surface plot of bte vs blend & CR

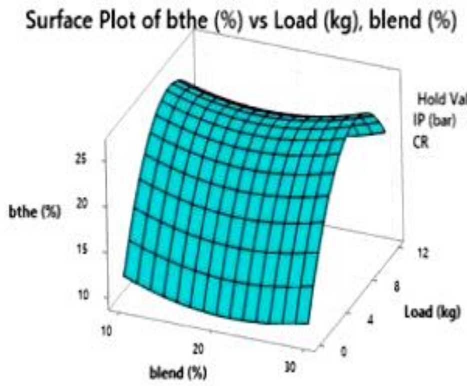

Figure 3.3 Surface plot of bte vs blend & Load

Jojoba blends cause BTE in diesel engines to decrease. This is due to the combined fuel's larger calorific value and viscosity than diesel, which eventually results in poor atomization and combustion. Additionally, it can be said that diesel fuel's lower heating value results in larger BTE.

The effect of load on BTE is interesting, by increasing load on the engine the BTE of the engine begins to increase this is because more load means more demand of fuel and proper atomisation of fuel takes place, engine performs to its maximum capacity level and hence proper burning of fuel takes place, more heat is generated in less amount of fuel, ultimately heat generated from fuel is efficiently converted into mechanical energy.

Compression ratio is another parameter which drastically affect the performance of the engine especially in the case of BTE. As compression ratio increase it means fuel mixture got compressed higher, high heat and proper combustion takes place, excellent atomisation of fuel mixture results in higher mechanical output in the same quantity of fuel mixture hence BTE increases significantly [10].

Injection pressure is another parameter which considerably affect engine performance. By increasing injection pressure, the brake thermal efficiency increases because it reduces both particulate and fuel consumption and increases the power of the engine.

Impact on EGT

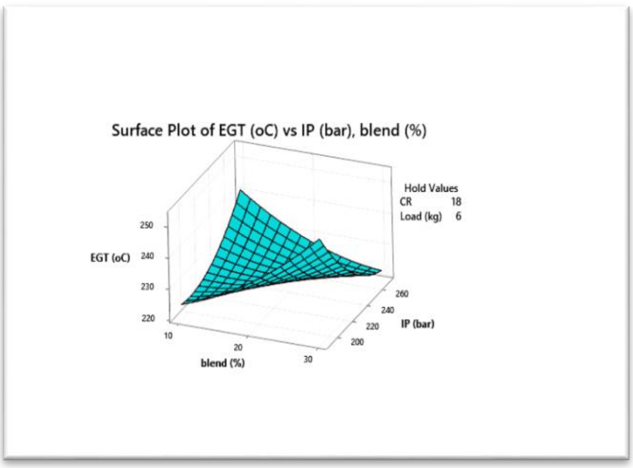

Figure 3.4 Surface plot of EGT vs blend & IP

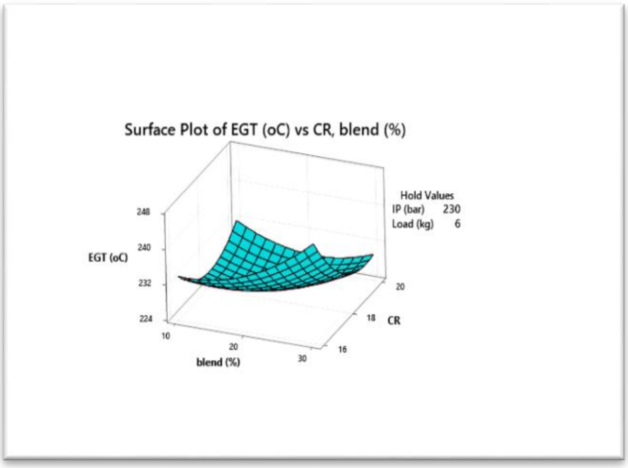

Figure 3.5 Surface plot of EGT vs blend & CR

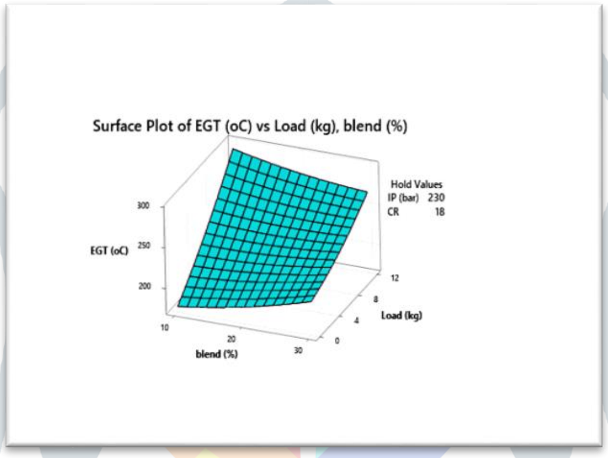

Figure 3.6 Surface plot of EGT vs load & blend

As it can be seen in the surface plot that increase in blend% from 10% to 30% causes increases in EGT it is because jojoba biodiesel has more oxygen molecules than diesel fuel, early fuel combustion occurs even though it has a lower heating value and is more viscous than pure diesel [11]. As the blend% increases fuel become more viscous and calorific value decreases, engine has to increase more power and burning of fuel does not takes place smoothly. Hence the value of EGT increase gradually.

Talking about effect of injection pressure on EGT, surface plot shows as the IP increases the value of EGT decreases, higher IP helps the fuel to be injected into cylinder through small nozzle orifice and reduce the injection duration, with the help of this mechanism better vaporisation of fuel takes place and hence the value of EGT decreases [12].

when blend% is increased from 10% to 30% the value of EGT is increasing gradually this is because jojoba oil is viscous in nature in spite of this it has low heat value and high oxygen content, these whole increases the temperature of the emission coming from the exhaust chamber.

In the next stage there is a variation of CR with respect to EGT, it is noted that when CR grows, EGT value first falls, and at greater compression ratios, such as from 18, as seen in the surface plot, it decreases albeit at a gradual rate. The volume of the cylinder divided by the volume of the combustion chamber is known as the compression ratio or BDC to TDC [13].

It is seen in the surface plot that as the value of blend% increases from 10% to 30%, the value of EGT increases because jojoba biodiesel is more viscous than pure diesel also it has low value of heat content and more oxygen content, due to this proper burning of fuel takes place whereas due to viscous nature of fuel more friction is created causing increase in the value of EGT [14].

Now the effect of Load is discussed, as the value of loading condition increases it is observed that the EGT increases rapidly, in addition to requiring more fuel to burn, a high load condition also raises the cylinder temperature, which permits burning more fuel and raises the exhaust gas temperature.

Emission analysis

Impact on CO

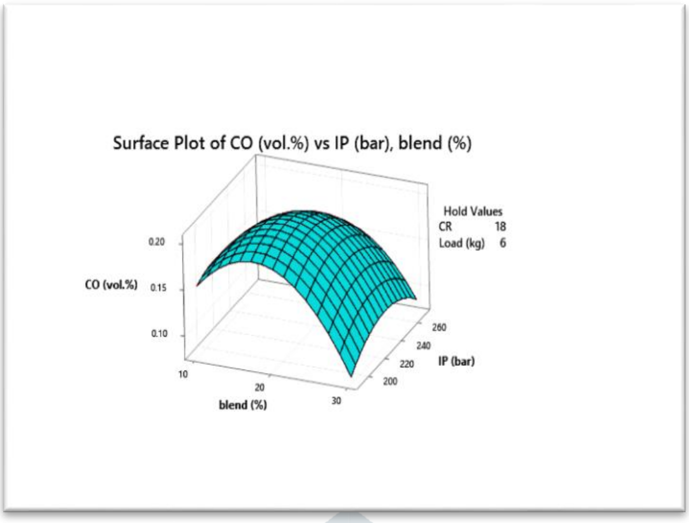

Figure 3.7 Surface plot of CO vs blend & IP

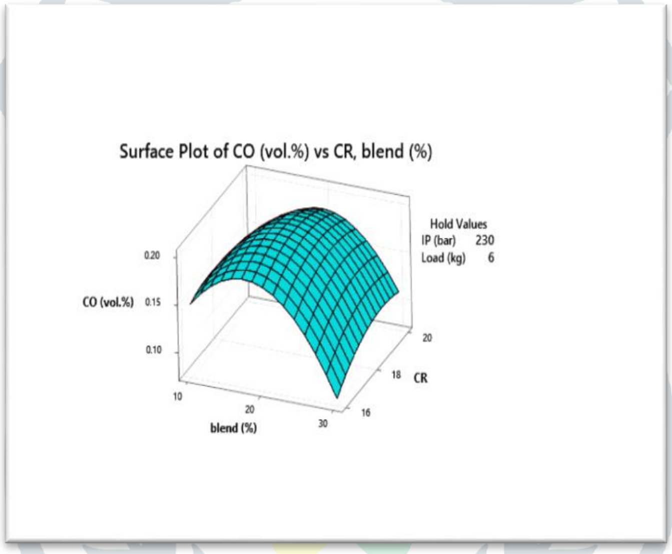

Figure 3.8 Surface plot of CO vs blend & CR

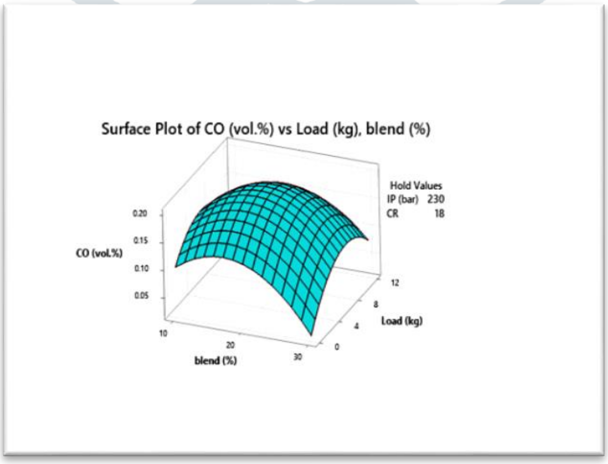

Figure 3.9 Surface plot of CO vs blend & load

Increasing blend% of jojoba oil decreases the concentration value of harmful CO up to certain extent though the value increases initially slightly this is due to load value of 6kg in input variable which is considered as high. Because jojoba biodiesel contains more oxygen than conventional diesel fuel, there are fewer carbon monoxide emissions as a result of the increased use of biodiesel.

The reason of decreasing value of CO due to increase in IP (bar) is because high injection pressure ensures high atomization of dense fuel diesel which results in better thermal combustion and explosion results in lower emission of CO as it is known that a good combustion always lower the emission of CO.

The sudden drop in the value of CO after the halfway point is caused by the higher concentration of blend%, which increases the amount of oxygen molecules in the biodiesel [15].

In the case of CR effect, the value of CO decrease is because the higher the compression ratio ensures better compression of diesel fuel which increases the temperature and excellent explosion of fuel takes place and it is known that better explosion and combustion of fuel results in lower emission of CO [16].

As the blend% increases the value of CO will decrease as shown clearly in the graph, the value of CO drops significantly at 15%. This is due to the high oxygen molecule content in jojoba biodiesel fuel, which guarantees effective fuel combustion and, as a result, lowers CO emission, it is already known that the improper burning of fuel results in the higher emission of CO.

The next variation is of CO with loading condition, as it can be seen in the graph that as the loading condition increases from 0 to 12 kg, the value of CO increases rapidly as it is known that the loading condition affects the CO value the most the reason behind the higher emission of CO as the load increases is because as higher load means higher amount of fuel used and consequently higher fuel used means higher emission but at very high loading condition as in the above graph the value of CO decrease slightly it is because higher loading condition means increased cylinder liner temperature which allows better fuel burn and ultimately the value of CO decreases.

Impact on NOx

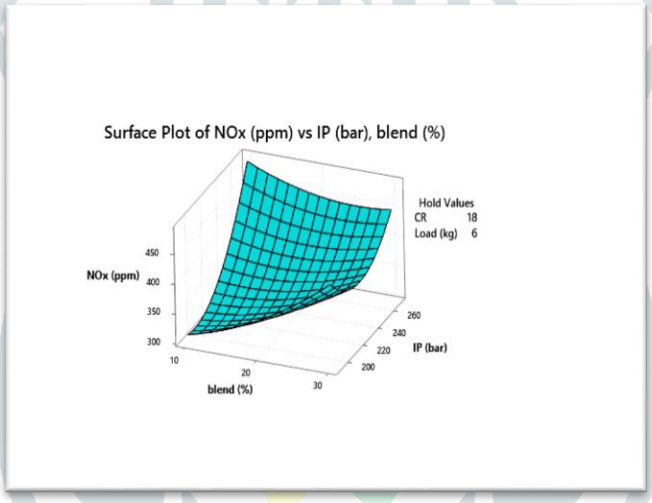

Figure 3.10 Surface plot of NOx vs blend & IP

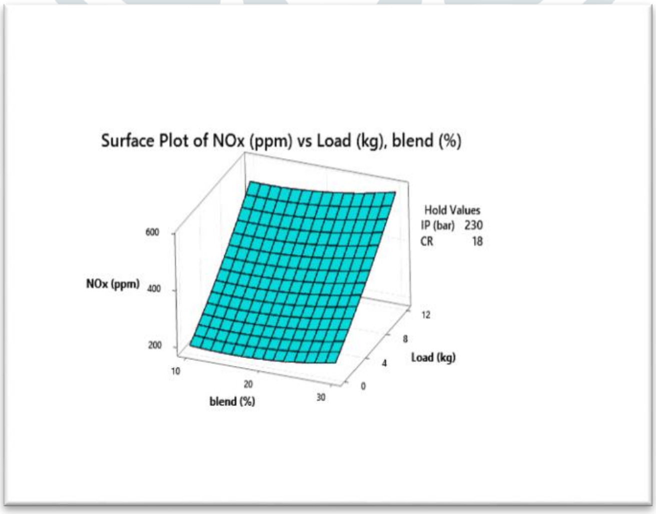

Figure 3.11 Surface plot of NOx vs blend & load

As in the above graph the value of NOx emission increases drastically, this is because jojoba biodiesel has a high cetane number and a high oxygenated molecule; as a result, a high inline cylinder temperature is achieved as high oxygen results in better fuel burning [17].

Now, considering the impact of injection pressure on NOx emission, it can be seen from the surface plot above that, after 220 bar of injection pressure, the value of NOx emission increases quickly because increasing injection pressure shortens the injection pressure, increases the fuel density, and improves the fuel spray, all of which lead to excellent fuel combustion.

The load has a significant impact on the NOx emission. This is owing to the fact that as loading conditions rise, the combustion chamber's temperature rises in order to produce more power [18] and it is well-known that an increase in cylinder temperature during combustion tends to raise the value of NOx emission.

IV. Conclusion

It was concluded that as jojoba blend% increases the brake thermal efficiency decreases slightly. Injection pressure causes to increase in the value of brake thermal efficiency. Again, compression ratio first decreases the brake thermal efficiency and then increase. Apart from that the value of brake thermal efficiency increases as load increases. Exhaust gas temperature increases as jojoba blend increases, while it decreases with increase in injection pressure. Again, the value of EGT decreases as compression ratio increases, when load increases the value of EGT increases sharply. In the case of emission analyses the value of CO first increases slightly and then continuously decreases when jojoba blend increases. CO values first increases then decreases in the case when IP, CR and Load increases. Lastly the value of NOx increases when jojoba blend, injection pressure and load increases.

Nomenclature

BTE Brake thermal efficiency
CRDI Common rail direct injection
CI Compression ignition
CO Carbon monoxide
CRDI Common rail direct injection
EGT Exhaust gas temperature
KOH Potassium hydroxide
NO_x Oxides of nitrogen
RSM Response surface methodology

References

1. Gregory, E. (n.d.). Forbes Health. Retrieved from Jojoba Oil: Uses, Benefits And Side Effects: https://www.forbes.com/health/body/jojoba-oil
2. Suresh, M., Jawahar, C. P., & Richard, A. (2018). A review on biodiesel production, combustion, performance, and emission characteristics of non-edible oils in variable compression ratio diesel engine using biodiesel and its blends. Renewable and Sustainable Energy Reviews, 92, 38-49.
3. Vergel-Ortega, M., Valencia-Ochoa, G., & Duarte-Forero, J. (2021). Experimental study of emissions in single-cylinder diesel engine operating with diesel-biodiesel blends of palm oil-sunflower oil and ethanol. Case Studies in Thermal Engineering, 26, 101190.
4. Goga, G., Chauhan, B. S., Mahla, S. K., & Cho, H. M. (2019). Performance and emission characteristics of diesel engine fueled with rice bran biodiesel and n-butanol. Energy Reports, 5, 78-83.
5. Saravanan, A., Murugan, M., Reddy, M. S., & Parida, S. (2020). Performance and emission characteristics of variable compression ratio CI engine fueled with dual biodiesel blends of Rapeseed and Mahua. Fuel, 263, 116751.
6. Ma, Q., Zhang, Q., Liang, J., & Yang, C. (2021). The performance and emissions characteristics of diesel/biodiesel/alcohol blends in a diesel engine. Energy Reports, 7, 1016-1024.
7. Sharma, A., Ansari, N. A., Pal, A., Singh, Y., & Lalhriatpuia, S. (2019). Effect of biogas on the performance and emissions of diesel engine fuelled with biodiesel-ethanol blends through response surface methodology approach. Renewable Energy, 141, 657-668.
8. Krishnamurthy, K. N., Sridhara, S. N., & Kumar, C. A. (2018). Synthesis and optimization of Hydnocarpus wightiana and dairy waste scum as feed stock for biodiesel production by using response surface methodology. Energy, 153, 1073-1086.
9. Khoobbakht, G., Najafi, G., Karimi, M., & Akram, A. (2016). Optimization of operating factors and blended levels of diesel, biodiesel and ethanol fuels to minimize exhaust emissions of diesel engine using response surface methodology. Applied Thermal Engineering, 99, 1006-1017
10. Kumar, M., & Ansari, N. A. (2021). Investigation of combustion, performance and emission of aluminium oxide nanoparticles as additives in CI engine fuels: a review. *Advances in Manufacturing and Industrial Engineering*, 1055-1063.
11. Hountalas, D. T., Mavropoulos, G. C., & Binder, K. B. (2008). Effect of exhaust gas recirculation (EGR) temperature for various EGR rates on heavy duty DI diesel engine performance and emissions. *Energy*, *33*(2), 272-283.
12. Basaran, H. U., & Ozsoysal, O. A. (2017). Effects of application of variable valve timing on the exhaust gas temperature improvement in a low-loaded diesel engine. *Applied Thermal Engineering*, *122*, 758-767.
13. An, H., Yang, W. M., Chou, S. K., & Chua, K. J. (2012). Combustion and emissions characteristics of diesel engine fueled by biodiesel at partial load conditions. *Applied Energy*, *99*, 363-371.

14. Monyem, A., & Van Gerpen, J. H. (2001). The effect of biodiesel oxidation on engine performance and emissions. *Biomass and bioenergy*, *20*(4), 317-325.
15. Vinayagam, N. K., Hoang, A. T., Solomon, J. M., Subramaniam, M., Balasubramanian, D., EL-Seesy, A. I., & Nguyen, X. P. (2021). Smart control strategy for effective hydrocarbon and carbon monoxide emission reduction on a conventional diesel engine using the pooled impact of pre-and post-combustion techniques. *Journal of Cleaner Production*, *306*, 127310.
16. McCormick, R. L. (2007). The impact of biodiesel on pollutant emissions and public health. *Inhalation Toxicology*, *19*(12), 1033-1039.
17. Al-Dawody, M. F., & Bhatti, S. K. (2013). Optimization strategies to reduce the biodiesel NOx effect in diesel engine with experimental verification. *Energy conversion and management*, *68*, 96-104.
18. Palash, S. M., Kalam, M. A., Masjuki, H. H., Arbab, M. I., Masum, B. M., & Sanjid, A. (2014). Impacts of NOx reducing antioxidant additive on performance and emissions of a multi-cylinder diesel engine fueled with Jatropha biodiesel blends. *Energy Conversion and Management*, *77*, 577-585.