Set-up of the Experiment and Improve the Performance and Emissions of Diesel Fuel with Fusel Oil Additive from Waste Products

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ABSTRACT

Response surface methodology has been widely implemented to improve the pollutant emission characteristics and performance of a compression ignition engine. The fusel oil-biodiesel blend and pure diesel under varied engine loads and speeds with the use of Models of RSM were found to be statistically significant. This research study has aimed to statistically investigate how a fusel oil-diesel blend impacts compression ignition engine performance and the exhaust pollutants by comparing it to pure diesel fuel. The optimum parameter for reducing ISFC, NOx and CO_2 emissions while boosting power was chosen. The blended fuel (F20) showed insignificant effects on the IP thereby 20% of fusel oil with diesel may be an acceptable ratio using CI engines in terms of power as well as the lowest NOx emissions with F20. Meanwhile, the highest values of ISFC and CO_2 emissions were with F20. When comparing diesel to F20, the optimal load was 29.4 % and the engine speed was 2399 rpm. The predicted values for power, ISFC, NOx and CO_2 emissions were 4.06 KW, 220.07 g/KWh, 55.56 ppm and 1.93% respectively.

Keywords: Fusel oil; RSM; Compression ignition engine; Engine performance; Engine emissions.

Nomenclature

CO Carbon monoxide	F0 Pure diesel
CO_2 Carbon dioxide	F20 20% vol. fusel oil and 80% vol. pure diesel
NOx Nitrogen oxides	DoE Design of Experiments
HC burned hydrocarbon	DI Direct injection
H_2 Hydrogen	ED Emulsified diesel
NG Natural gas	ppm Parts per million
LPG Liquefied petroleum gas	RPM Revolutions per minute
ISFC Indicated specific fuel consumption	ASTM American society for testing material
SI Spark ignition	IP Indicated power
	ANOVA Analysis of variance
IC Internal combustion	MTBE Methyl Tertiary Butyl Ether
SI Spark ignition	DME Dimethyl Ether
ISFC Indicated specific fuel consumption	3D Three dimensions
RSM Response surface methodology	PC Percentage contribution
DF Degree of freedom	R^2 Coefficient of determination

INTRODUCTION

Today's global energy demand is rising dramatically, and the situation will be even greater in the future. So, the need for energy security is becoming more significant worldwide. In the previous decades, the energy crisis occurred due to the considerable reduction of exhaustible energy resources (Othman et al., 2017). Thus, finding alternative energy sources and reduction in the sources of energy (fossil fuel) is considered as optimal solutions. In 2008, Baruch (Baruch, 2008) observed that the rise in population will cause a growing demand for energy, which is estimated to double by 2050. In many countries, numerous researchers have made great efforts to find appropriate alternative fuels that can be sustainable and have less impact on the environment. (Alenezi et al., 2013; García et al., 2011; Othman et al., 2017). Most worldwide transport fuels come from fossil-derived petroleum and some are shared with biofuels (Alenezi et al., 2010; Alenezi et al., 2013).

Design of Experiment (DoE) techniques have been implemented to optimize the operating conditions such as biodiesel ratio, engine emissions, engine loads, air-fuel ratio and speeds, especially with other fuels so as to enrich the emission characteristics and performance of a compression ignition engine running on a by-product of a fusel oil-diesel blend and pure diesel. It is a useful and an economical solution for designing experiments. Among all DoE techniques, the Response Surface Methodology (RSM) is the best and is widely applied to assess multiple and single factors of test variables that directly affectoutput reactions (Bezerra et al., 2008; Kulkarni et al., 2015). One of the main features of RSM is that it makes a comparison between an actual experimental data and a fewer simulation tests to ensure the best implementation for optimized sets in a time and cost efficient way (Ma et al., 2015). This technique is extensively implemented in numerous industrial and research investigations. RSM has recently been used to enhance performance and alleviate exhaust emissions in SI engine from secondary butyl alcohol-gasoline mixes. (Yusri et al., 2017). In another study by Najafi et al. (2015), RSM was utilized in order to optimize the engine operating parameters. Khan and Joshi (2015) found that RSM has more precise models as they account for kinetic energy radial convection. The term 'alternative fuel' describes any fuel used in the transportation sector other than conventional fossil fuel. Biodiesel fuel is a popular replacement to petroleum diesel, and it is widely used in many countries. The transesterification process of vegetable oil or animal fat with alcohols such as methanol, ethanol and propanol, produces biodiesel. The feed stocks are mainly vegetable oils, which can be acquired from a diverse range of plants such as sunflower, palms, rapeseeds, corn and others. In addition, alternative fuels contain gas fuels like NG, H_2, and LPG. Alcohols like ethanol, butanol, and methanol, as well as MTBE or DME, can be made use of as substitute fuels (Arcoumanis et al., 2008; Pourkhesalian et al., 2010; Semelsberger et al., 2006). Numerous researchers have directly considered the use of various types of alcohols in SI engines as a substitute fuel or as a fuel additive. Alcohol heating values are lower than gasoline. As a result, when alcohol is used as a substitute for fuel in SI, fuel consumption rises on a regular basis (Chen et al., 2010; Gravalos et al., 2013; Masum et al., 2013; Scragg, 2009). Yücesu et al., (2006) found that ethanol when mixed with gasoline decreased emissions of both CO and HC. The reduction of CO and HC emissions were produced by the wide oxygenated characteristics and flammability of ethanol. Moreover, similar outcomes were obtained when utilizing the methanol–gasoline blends (Agarwal et al., 2014; Hu et al., 2007; Siwale et al., 2014).

Due to environmental concerns regarding the fast depleting reserves of global fossil oil, interest in using biofuel in compression-ignition engines is increasing. Furthermore, the environmental implications of fossil fuel had caused a rise in the cost of fossil fuels as well as a limit imposed on the fumes generated by IC engines. A number of countries have now used renewable fuels to substitute fossil fuel (Alenezi et al., 2009; Eyidogan et al., 2010). As a result, the alcohols, either blended with or added to gasoline and diesel, are used in internal combustion engines as a form of replacement for fossil fuel (Atmanlı et al., 2015). Furthermore, to reduce the greenhouse effects and to prevent the consequences of global warming, 200 countries have reached a collective agreement in December 2015 (Hulwan and Joshi, 2011). It was discovered that the utilization of alcohols in combination with diesel fuel alters some of its characteristics in terms of cetane number, moisture content, heating value, viscosity, and blending stability; thus, indicating that alcohols affect the features, the functioning, and the exhaust emissions of engine combustion (Atmanlı et al., 2015; Eyidogan et al., 2010; Sayyed et al., 2021). Numerous researches have demonstrated that using diesel-alcohol blends in CI engines increases the ignition interval duration of the combustion process (Hulwan and Joshi, 2011; Sharma and Murugan, 2015). However, the type of alcohol used influences the ignition delay period as it gets prolonged because of the rise of alcohol amount in the diesel-alcohol blends. A significant improvement in emissions is observed when alcohol is used as a blend with diesel.

When bioethanol is produced through a fermentation process, fusel oil (a natural source of amyl alcohols) is created as a by-product (Dörmő et al., 2004; KÜÇÜCÜK and Ceyln, 1998; Özgülsün et al., 2000). In Brazil, the production of fusel oil is generally based on 0.25 L of fusel oil for each 100 L of ethanol (Ferreira et al., 2013). Meanwhile, in Turkey, for every 100 L of alcohol created, 0.2–0.35 L of fusel oil is produced (Anonymous, 2013; Ferreira et al., 2013). The properties found in fusel oil allow it to perform efficiently in a gasoline engine, making it a suitable substitute fuel. In the production of alcohol, the process of its fermentation, the method of its preparation as well as a method of its decomposition, the constituents and the number of fuel hinges on the type of carbon used. Table 1 indicates the components of fusel oil namely isobutyl alcohol, n-propyl, methyl alcohol, iso-amyl alcohol, and ethyl alcohol (Icingur and Calam, 2012). The usage of fusel oil as a blend with gasoline has been demonstrated to enhance the engine performance and the exhaust emission, according to many studies (Calam et al., 2014; Icingur and Calam, 2012; Karaosmanoğlu et al., 1997).

As a result of its usefulness and being a supplement fuel in compression ignition engines, fusel oil is likely to be recognized as an innovative source of fuel for internal combustion engines. Although only a few literatures are available upon the investigation of fusel oil with diesel blends, there are several incomplete studies which explored the utilization of gasoline in spark ignitions. This study aims to statistically compare the effects of fusel oil-diesel blend on compression ignition engine performance and exhaust emissions to pure diesel fuel. The experiments were performed at different engine speeds, fuel ratios and engine loads. The optimum parameter was selected in order to minimize the ISFC, NOx, CO_2 emissions and maximize the power.

Table 1. Major components of fusel oil (Calam et al., 2015).

Com ponents	.Ch emical formula	Mo lecular weight	D ensity (g/cm^3)	B oiling point (˚C)	Fr eezing point (˚C)	% Volumetr ical	Molar %
i- amyl alcohol	C_5 $H_{12}O$	88. 14	0. 8104	1 31.1	−1 17.2	6 3.93	6 1.52
i- butyl.alcohol	C_4 $H_{10}O$	74. 12	0. 802	1 08.0	−1 08.0	1 6.66	1 5.87
n- butyl alcohol	C_4 $H_{10}O$	74. 12	0. 810	1 17.7	−8 9.5	0 .736	0 .71
n- propyl.alcohol	C_3 H_8O	60. 09	0. 803	9 7.1	−1 26.5	0 .738	0 .70
Etha nol	C_2 H_6O	46. 07	0. 789	7 8.4	−1 14.3	9 .58	8 .98
Wate r	H_2 O	18. 00	1. 0	1 00	0. 0	1 0.30	1 2.23

METHOD AND MATERIAL

Set-up of the Experiment

In this study a YANMAR TF120M single cylinder engine, with a 17.7 Compression and ratio of 0.63 L was the tested diesel engine. Figure 1, shows the experimental setup of the engine utilized in this study. Using a TFX Engineering DAQ system consisting of a crank angle sensor and a cylinder pressure sensor, the data were recorded. The temperature of the ambient air and the temperature of the exhaust gas emission were calculated by using K-type thermocouples and saved by using the data logger of Pico thermocouples. The thermocouples were installed at the air measurement unit and the exhaust manifold, and the emissions were measured with a Kane auto 4-1 series exhaust gas analyser. The experiment was carried out at five different speeds ranging from 1200 to 2400 rpm with 300 rpm intervals and three engine loads of 25%, 50% and 75%. F0 and fusel oil-diesel blend (F20) were used in the tests. Fusel oil has a water content of around 13.5%. Furthermore, its heating value is lower than that of diesel as illustrated in Table 2.

The research study was conducted in controlled conditions and began with pure diesel to warm up the engine and obtain baseline data. The parameters of ISFC, engine power and torque, the exhaust temperature and the emissions (NOx and CO_2) were investigated through this experiment.

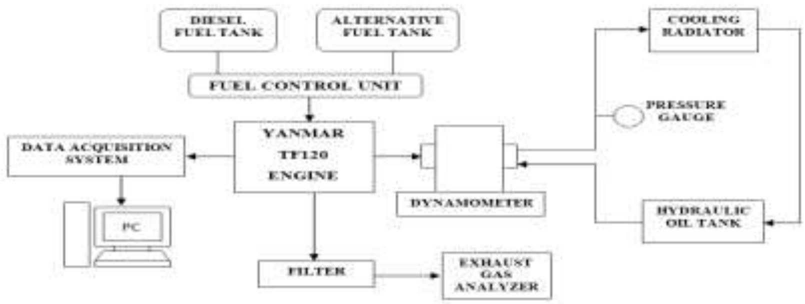

Figure 1. Schematic diagram of the experimental arrangement of Yanmar TF 120.

Test Fuels

A mixture of a F0 with F20 were utilized in the experiment. In this investigation, the two fuel blends used, were sited at ambient temperature for a period of 48 hours. No separation phase changes were noticed during this period. Most of the fuel blends properties such as density, moisture content, boiling point and heating value for F20 diesel and fusel oil were analysed at the University Malaysia Pahang (UMP) in the chemical engineering laboratories. Furthermore, for the pure diesel, cetane number was acquired from Yasin et al., (2014). All the properties of the tests fuel are displayed in Table 2.

Table 2. The properties of the used fuel.

	Properties of fuel L		Di		Fu		F2
		esel		sel oil		0L	
	Density [Kg/m^3]		74		84		76
		6		7		1	
	Higher.heating value		47		29		42
MJ/kg		.5		.5		.12	
	Cetane Number		46		-		-
		.0					
	Moisture content %		-		13		0.
				.5		88	
	Boling point [°C]		-		98		20
				.0		1	

Design of the Research Surface Method analysis

RSM is a beneficial technique for several engineering field (Box and Wilson, 1992; Kulkarni et al., 2015; Montgomery, 2013). It is a series of statistical approaches that use square polynomial functions or linear functions to define the response relationship with its input variables beside the purpose of maximizing or minimizing the response's attributes. Moreover, in RSM, the user-defined designs that were used included all points from a specified candidate set. If continuous factors are utilized, the candidate set will be based upon the best points to suit a polynomial model. User-defined levels can also be used to generate the candidate set. The discrete function has been applied for matching the parameter used in this experiment. The discrete function outlines the factor scenarios which are accessible to the trial for an else constant factor. The use of the discrete factor settings simplifies the experiment while limiting the effect on the strength of the investigation.

In the current investigation, there are three influential factors namely, load (%), fuel ratio blends (%vol.) and speed (rpm). A total number of 30 runs were set up for this experiment by varying between five engine speed levels, three engine load levels and two fuel ratio levels. Table 3 presents the independent variables and their related levels and codes. The IP (KW), the indicated specific fuel consumption ISFC (g/KWh), the carbon dioxide CO_2 emissions (% vol) and the nitro oxide NOx emissions (ppm) were all identified during the testing. In this investigation DF and F-value represents the probability distribution in repeated sampling, and Prob stands for weight of significance in this investigation. The P-value is the difference between the tested samples for a definite property, and the outcome is regarded significant if the value of Prob > F is fewer than the significance level. The confidence range for the significance level was established at 95% (Prob > F to be maximal at 0.05). In this study, Design Expert Version 10 software was utilized for the analysis and design. The percentage contribution (PC) is often irregular, but it is a good pointer of the relative significance of each term model (Othman et al., 2017). It is possible to calculate the percentage contribution as in Equation 1:

$$PC = \frac{SS_d}{SS_T} x100\% \quad (1)$$

where SS_T represents the total sum of squared deviations and SS_d represents the sum of the squared deviations.

This model that is implemented in RSM is founded on a linear function as presented in Equation 2:

$$Y = \beta_0 + \sum_i^k \beta_i X_i + \varepsilon \quad (2)$$

If there is any curvature in this model, a second-order model such as Equation 3 must be used:

$$Y = \beta_0 + \sum_i^k \beta_i X_i + \sum_{i<j}^k \beta_{ij} X_i X_j + \varepsilon \quad (3)$$

The quadratic model is appropriate for figuring out an important point of characteristic (maximum and minimum) in this present situation and then have a look (Alenezi et al., 2013), with the aid of using Equation 4:

$$Y = \beta_0 + \sum_i^k \beta_i X_i + \sum_i^k \beta_{ii} X_i^2 + \sum_{i<j}^k \sum \beta_{ij} X_i X_j + \varepsilon \quad (4)$$

where, k is the number of variables (in this study, k = 3), x_i, x_j and x_i^2 are the variables. β_0, β_i, β_{ii} and β_{ij} are the constant terms, the coefficients of the linear terms x_i, the coefficients of the quadratic terms x_i^2 and the coefficients of the interaction terms x_i, x_j, respectively. The residual linked with the experiments is related to ε. For multi-responses, the assortment of ideal parameter conditions can be made to improve engine performance and minimize emissions. It is possible to specify the estimated range for each engine reaction as well as the parameter range and to also determine all engine responses. The attractiveness function method was performed thru Design Expert v.10.1.3 software to optimize these parameters.

Table 3. levels and Parameters.

Factors	Process parameters	Level 1	Level 2	Level 3	Level 4	
A	Speed (rpm)	1200	1500	1800	2100	2400
B	Load (%)	25	50	75		
C	Fuel (%Vol)	F0	F20			

RESULTS AND DISCUSSION

The efficiency and emissions of the DI engine was studied using regression models developed from data acquired from the experimental design matrix.

Then, these models were assessed, reviewed, and adjusted to reduce the ISFC, the CO_2 and NOx emissions while also increasing the power.

ISFC, CO_2, NOx emissions and power.

In order to graphically confirm the normality assumption for the measured data, normal probability graphs were plotted (Su et al., 2016). One of the analytical plots was utilized to check the distribution of residuals. The residuals for ISFC, CO_2, NOx emissions and power follow a normal distribution which is a necessary requirement for the validity of analysis of variance (ANOVA) as seen in Figure 3. The other condition for ANOVA validation is the homogenous character of the variance, which was tested using the residual versus actual response plots as seen in Figure 3.

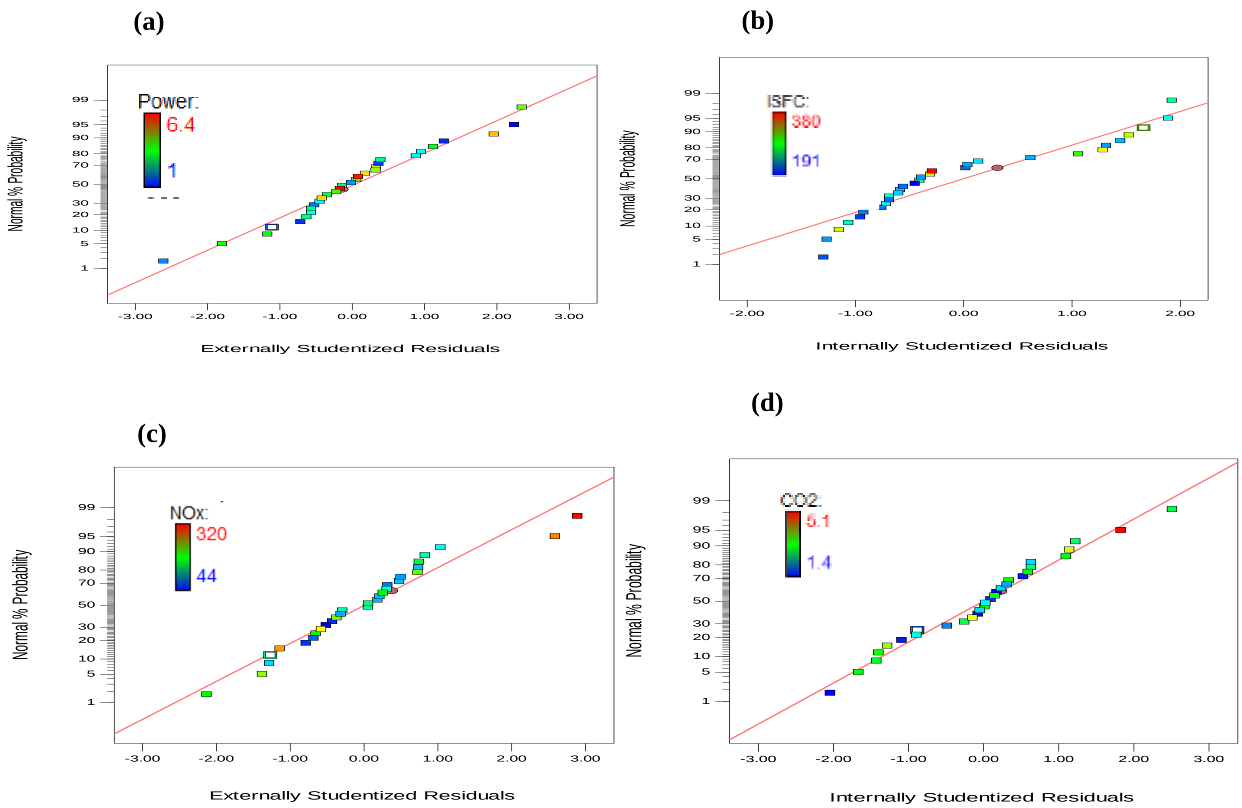

Figure. 2. Normal probability plots for (a) Power, (b) ISFC, (c) NOx emissions and (d) CO_2 emissions.

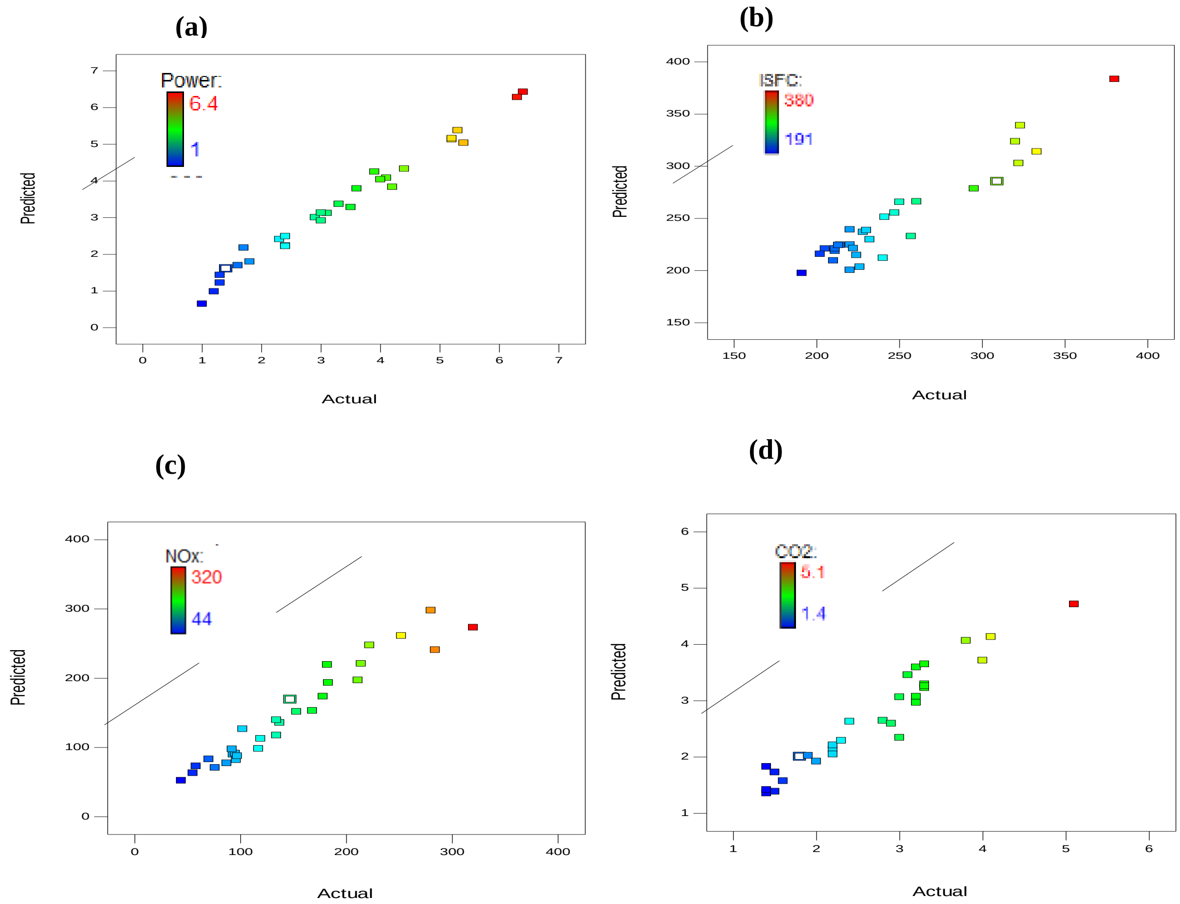

Figure. 3. Actual vs predicted values for (a) Power,(b) ISFC, (c) NOx emissions and (d) CO_2 emissions.

Table 4 illustrates the ANOVA data of the IP. The model F-value of 245.47 indicates that it is substantial. There is just a 0.01% possibility that a high F-value may be caused by noise. A substantial model by itself does not guarantee a definitive clarification of data differences. Based on the P-value, the ANOVA table showed that the speed load and fuel issues have important terms. Furthermore, R^2 value of 0.98 reflects the entire variability of responses after accounting for the significant factors and the number of the model's number of predictors as shown in Table 5. A high R^2 coefficient ensures that the calculated and observed data are in agreement (Noordin et al., 2004). The revised R^2 of 0.9806 is reasonably close to the predicted R^2 of 0.9715, therefore the variance is fewer than 0.2. Adeq precision method measures the signal-to-noise ratio. A ratio of more than 4.0 is recommended. An adequate ratio single is indicated with value of 55.033. The design space can be navigated using this model. The PC is frequently a useful indicator of each model term’s relative value (Noordin et al., 2004). It was discovered that the engine speed had the greatest contribution effects (71%) of the total variability on the IP over engine load (25%), while the blended fuel had minor outcomes on the power. According to Table 4, the influence of engine speed on IP was determined to be the greatest followed by engine load and fuel. The PC provided a clear understanding of parameter effects on the IP which were 71%, and 25%, for speed and load, respectively. The blended fuel (F20) has an insignificant effect on IP thereby 20% of fusel oil with diesel may be an acceptable ratio in CI engines in terms of power. Figure 5 depicts the combined effects of speed and load of CI engine on power.

Table 4. ANOVA table for IP.

Source	Sum of Squares	DF	Mean Square	F Value	p-value Prob > F	PC	
Model	69.55	6	11.59	245.47	< 0.0001	98%	significant
A-Speed	50.42	1	50.42	1067.67	< 0.0001	71%	significant
B-Load	17.48	1	17.48	370.27	< 0.0001	25%	significant
C-Fuel	0.43	1	0.43	9.15	0.006	1%	significant
AB	1.12	1	1.12	23.77	< 0.0001	2%	significant
AC	0.081	1	0.081	1.71	0.2041	0%	insignificant
BC	0.013	1	0.013	0.26	0.6118	0%	insignificant
Residual	1.09	23	0.047			2%	
Cor Total	70.63	29				100%	

Table 5. Fit Statistics table of IP.

Std. Dev.	Mean	C.V. %	R^2	Adjusted R^2	Predicted R^2	Adeq Precision
0.217	3.250	6.68	0.984	0.980	0.9715	55.032

Due to the linear model's considerable lack of fit, the data was better suited to a quadratic model for IP. In terms of concrete factors, the equation can be employed to forecast each factor's response for the given levels. Equation 5 presents a regression model for F0.

$$\begin{aligned} IP = & -1.81667 + 0.00181667 \text{ x Speed} + -0.0018 \text{ x Load} \\ & + 0.0000223333 \text{ x Speed x Load} \end{aligned} \quad (5)$$

Equation 6 presents a regression model of IP for the fusel oil-diesel blend (F20)

$$\text{IP} = -2.39667 + 0.00206111 \text{ x Speed } + -0.0038 \text{ x Load } + 0.0000223333 \text{ x Speed x Load} \quad (6)$$

The 3D surface plot was designed to recognise the collaboration effects between variables and responses. Figure 4 shows a 3D surface plot showing the effects of speed and load on the IP. It was discovered that the IP was greatly affected by the engine speed than the engine load. The plots illustrate that the value of power was maximum when the value of the speed and the load were at its highest. Clear significant changes in the surface plot can be seen when the speed changes from a lower to a higher value but is only slightly effected when the load was changed. The counter surface in Figure 5 suggests the flavoured regain which represents the high power obtained at the condition speed ranging between 2100–2400 rpm, and at a load ranging between of 65–75%.

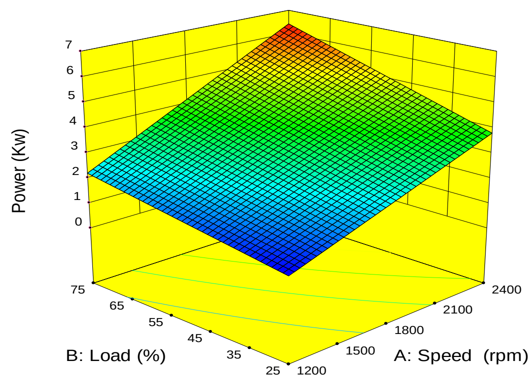

Figure 4. A 3D surface plots of engine loads against Engine power and speeds.

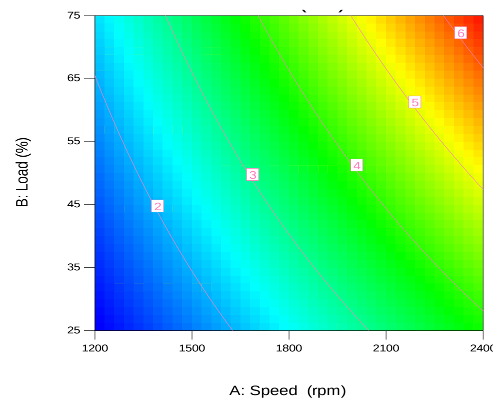

Figure 5. Power plots counter surface against engine loads and speed.

Table 6 illustrates the ANOVA data of ISFC. The p-value is lower than 0.0001 thereby the model is of significance. The ANOVA table stated that, according to the P-value, the speed, load and fuel factors have significant terms. Furthermore, as shown in Table 7, an R^2 value of 0.98 reflects the total variability of responses after accounting for the number of predictors and significant factors in the model. A high R^2 coefficient ensures that the data calculated and observed are in agreement. The Predicted R2 of 0.7994 is quite close to the Adjusted R2 of 0.8731, with a difference of less than 0.2. It was shown that the engine speed has greatest contribution effects (47%) of total variability on the ISCF than engine load (12%), while the blended fuel has lower effects on ISFC which was at 11%. The effects of engine speed on ISFC were found to be greatest, followed by engine load and fuel blend, as shown in ANOVA from Table 4. Because fusel oil has a lesser energy content than diesel, the blend (F20) will eventually have a lower calorific value when combined with diesel (from Table 2). As a result, the engine would need more blend than diesel to achieve the rated power.

Table 6. ANOVA table for ISFC.

So urce	Su m of Sq uares	F I	Me an Sq uare	F V alue	p- value P rob > F	PC

Model	59981.01	8	7497.63	25.94	< 0.0001	91%	significant
A-Speed	30794.94	1	30794.94	106.55	< 0.0001	47%	significant
B-Load	7784.32	1	7384.32	25.55	< 0.0001	12%	significant
C-Fuel	7121.62	1	6621.62	22.91	< 0.0001	11%	significant
AB	3245.4	1	3245.4	11.23	0.003	5%	significant
AC	2144.43	1	2144.43	7.42	0.0127	3%	insignificant
BC	190.34	1	190.34	0.66	0.4262	0%	insignificant
A2	9487.06	1	9487.06	32.82	< 0.0001	14%	significant
B2	112.89	1	112.89	0.39	0.5387	0%	significant
Residual	5269.43	21	289.02			8%	
Cor Total	66050.43	29				100%	

Table 7. Fit Statistics table of ISFC.

Std. Dev.	Mean	C.V %	R^2	Adjusted R^2	Predicted R^2	Adeq Precision
17.000	248.540	6.84	0.908	0.873	0.799	19.900

In the response surface plots and the contour plots, the reddish and bluish areas indicate the lowest possible ISFC's with the highest engine speed and load as demonstrated in Figure 6. As shown in the counter surface plot (Figure 7), the desired regain represents a lower ISFC attained at a condition speed ranging between 2100 and 2400 rpm and the load ranging between 65 and 75%.

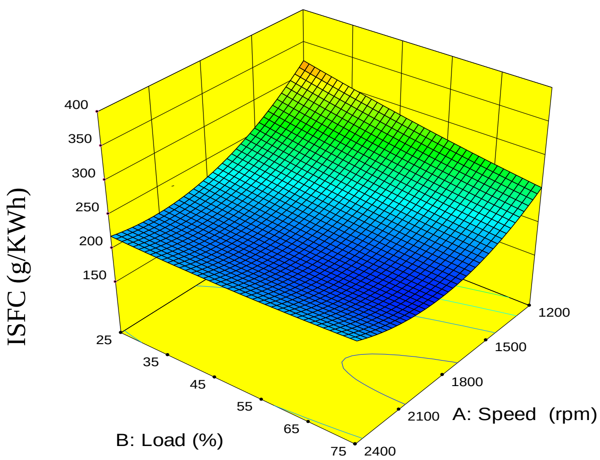

Figure 6. 3D surface plots of ISFC against engine speeds and loads.

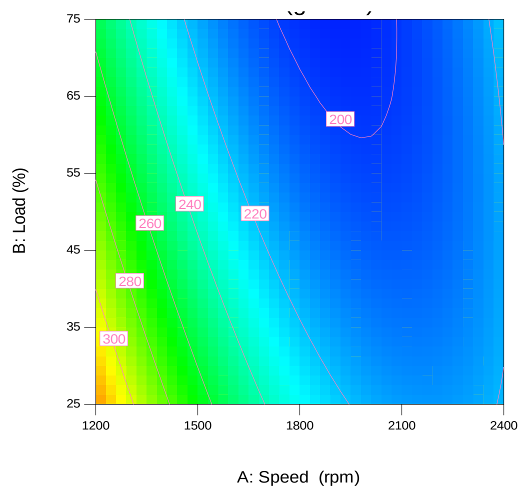

Figure 7. Counter surface plots of ISFC against engine speeds and loads.

Table 8 illustrates the ANOVA data of NO_x emission. The model is substantial since the p-value is smaller than 0.0001. The ANOVA table demonstrats that the load, speed and fuel factors have significant terms based on the P-value. In addition, the R^2 value of 0.98 represents the total variability of responses after accounting for significant factors and the number of predictors in the model, as shown in Table 9. A high R^2 coefficient indicates that the calculated and observed data are in good conformity. The Predicted R^2 of 0.7829 is in reasonable agreement with the Adjusted R^2 of 0.8179, with a difference of less than 0.2. A high R^2 coefficient ensures that the data calculated and observed are satisfactorily agreed. The engine load was seen to have the supreme influence effects (74%) of total variability on the NOx emissions compared to the engine speed (12%), whereas the blends fuel has less NOx emission effects of 5%.

Table 8. ANOVA table for NO_x emissions.

So urce	Su m of Squ ares	f	Me an Squ are	F V alue	p- value Prob > F			
Mo del	1.4 6E+05	[illegible]	487 52.16	4 4.43	< 0.0001	4%	8	signi ficant
A- Speed	205 18	[illegible]	163 02.02	1 4.86	0. 0007	2%	1	signi ficant
B- Load	1.2 9E+05	[illegible]	1.2 9E+05	1 17.39	< 0.0001	4%	7	signi ficant
C- Fuel	795 3.2	[illegible]	115 3.2	1. 05	0. 1147	%	5	signi ficant
Re sidual	175 28.2	[illegible] 6	109 7.24			0%	1	

Co r Total	1.7 5E+05	9		1 00%

Table 9. Fit Statistics table of NO_x

St d. Dev.	Me an	C. V. %	R^2	Adju sted R^2	Predi cted R^2	Adeq Precision
33 .12	14 8.33	22 .33	0. 838	0.81 7	0.782	19.7

Figure 8 shows the NOx emission in a 3D surface plots against engine velocity and load. It is clear from the 3D surface plot that the engine's load has a major outcome as the value of the NOx increases. With larger engine loads and lower engine speeds, the bluish and reddish areas in the response surface plots, as shown in Figure 9, indicate the highest probable NOx emissions.

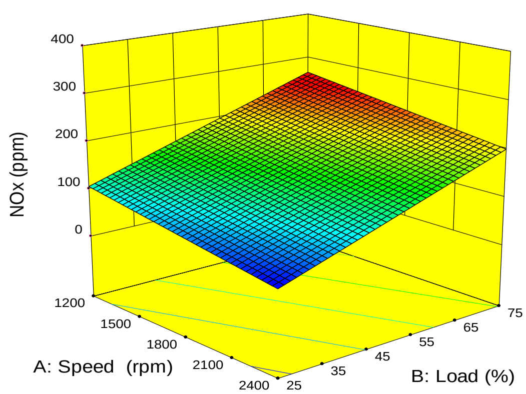

Figure 8. 3D surface plots of NO_x against engine speeds and loads.

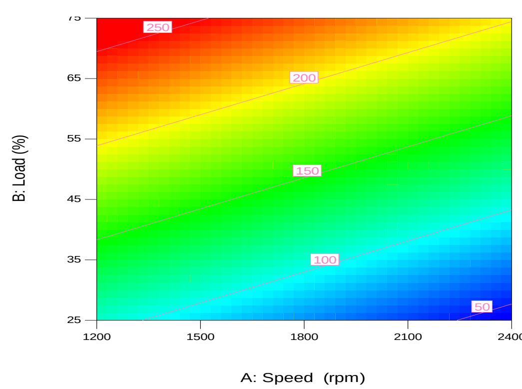

Figure 9. Counter surface plots of NO_x against speeds and loads.

Table 10 illustrates the ANOVA data of CO_2 emission. The p-value of under 0.0001 shows that the model is of significance. The ANOVA table revealed that the factors of load, speed and fuel have significant terms based on the P-value. In addition, an R^2 value of 0.93 indicates the total response variability after considering the important factors and the value of the model's number of predictors as shown in Table 11. The Predicted R^2 of 0.8449 is in good agreement with the adjusted R^2 of 0.9055, with a difference of less than 0.2. A high R^2 coefficient ensures that the data calculated and observed are satisfactorily agreed. The engine load was seen to contribute the highest effects (60%) of total variability on the CO_2 emission compared to the engine speed (18%), whereas the blended fuel has lesser impacts on the CO_2 emissions of 7%.

Table 10. ANOVA table for CO_2 emissions.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F		
Model	23.56	8	2.94	35.73	< 0.0001	93%	significant
A-Speed	4.48	1	4.48	54.39	< 0.0001	18%	significant
B-Load	15.14	1	15.14	183.67	< 0.0001	60%	significant
C-Fuel	1.83	1	1.83	22.15	0.0001	7%	significant
AB	0.1	1	0.1	1.21	0.2832	0%	insignificant
AC	0.77	1	0.77	9.35	0.006	3%	significant
BC	0.45	1	0.45	5.46	0.0294	2%	insignificant
A^2	0.19	1	0.19	2.31	0.1434	1%	insignificant
B^2	0.6	1	0.6	7.28	0.0135	2%	insignificant
Residual	1.73	21	0.082			7%	
Cor Total	25.29	29				100%	

Table 11. Fit Statistics table of CO_2.

Std. Dev.	Mean	C.V. %	R^2	Adjusted R^2	Predicted R^2	Adeq Precision
0.28	2.68	10.71	0.931	0.905	0.844	21.37

The 3D surface plots of CO_2 emissions against engine speeds and loads are shown in Figure 10. The 3D surface plot evidently shows that the engine load is significantly affected as the value of CO_2 emissions increases. The reddish and bluish areas in the response surface plots indicate the lowest possible CO_2 emissions with lowest engine speed ranges between 1200 to 1500 rpm, at a load of 25%.

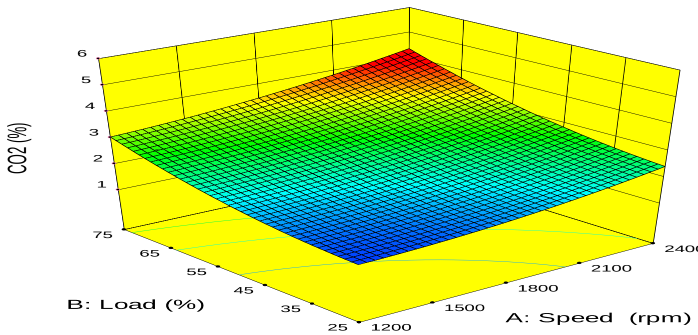

Figure 10. 3D surface plots of CO_2 against enginespeeds and loads.

Optimization

Since there is a trade-off among power, ISFC, NO_x emissions and CO_2 emissions, fuel ratio (blend type), engine load and speed need to be optimized. The goal is to reduce the emissions of NOx and CO_2 while keeping the ISFC to a minimum. A desirability function was performed to obtain optimum multi-response parameters. Table 12 provides an instant for all the criteria used to identify the constraints and optimal settings for the multi-objective optimization technics. The optimum conditions were set within the range for input factors (fuel ratio engine and parameters). It is assumed that the four types of response features are correspondingly important in this study (weight w =1:1:1:1). Moreover, Table 12 indicates the optimal settings for parameters to attain the response goals. Analysis of attractiveness was completed with the larger-the-better attractive function on the response value. In order to achieve the highest desirability value, the optimal condition was chosen. Table 13 labels the outcomes of the multi-optimization analysis. A complete of 12 desirable outcomes have been attained and the best options have been chosen for near-1 desirable solutions.

Table 12. Optimization constraint for the response features and cutting parameters.

Item	GoalL	Lo wer LimitL	Up per LimitL	Lo wer WeightL	Up per WeightL	nceL	Importa
A:Sp eed	is in range	12 00	24 00	1	1	3	
B:Lo ad	is in range	25	75	1	1	3	
C:Fu elL	is in range	F0	0 F2	1	1	3	
Pow er	maxi mize	1	6.4	1	1	3	

	ISFC	minimize	1	190	38	1	1	3
L	NOx	minimize		440	37	1	1	3
	CO_2	minimize		1.4	5.1	1	1	3

Thus, the best solution was with diesel at the highest speed and a medium engine load but for F20 it was solution number 11 with a higher engine speed. Solution 1 was prefered with 0.707 desirability value. Furthermore, this choice resulted in the greatest feasible combined power, ISFC NO_x and CO_2 emissions. Table 14 shows that the best condition of parameters with diesel compared to F20 was 29.4 percent for engine load and 2399 rpm for engine speed. Additionally, the anticipated values were 4.06 KW, 220.07 g/KWh, 55.56 ppm and 1.93% for power, ISFC, NO_x and emissions of CO_2, respectively.

Table 13. A solution for work material with optimized cutting parameters.

Number	Speed	Load	Fuel	Power	ISFC	NOx	CO_2	Desirability
1	2399.999	29.433	F20	4.068	220.079	55.547	1.93	0.794
2	2399.988	29.458	F20	4.069	220.073	55.628	1.931	0.794
3	2399.992	29.657	F20	4.08	220.035	56.265	1.936	0.794
4	2399.979	29.204	F20	4.056	220.123	54.814	1.924	0.794
5	2399.983	29.999	F20	4.097	219.97	57.364	1.945	0.794
6	2399.989	30.468	F20	4.122	219.883	58.87	1.957	0.794
7	2399.972	31.408	F20	4.17	219.717	61.888	1.982	0.794
8	2399.974	27.163	F20	3.95	220.555	48.261	1.876	0.793
9	2399.995	33.331	F20	4.27	219.417	68.06	2.035	0.793
10	2400	37.5	F20	4.486	218.931	81.442	2.164	0.788

1 1	2 384.697	3 2.852	I 20	4 .143	2 29.155	5 4.962	3 .146	0.6 98
1 2	2 382.731	3 3.028	I 20	4 .146	2 29.039	5 5.636	3 .146	0.6 98

Figure 12 displays the contour graphs of the power, ISFC, NO_x and CO_2 emissions for the selected solution after multi-optimization at the highest desirability value. Figure 12 shows the desirability value which is like the expected values of parameters for multi-objective optimization. Figure 12 (B) displays that the power increases as the engine loads and speeds increased. So, at 75% load and 2400 rpm speed the most power was generated. The minimum NOx emission value was at the minimal engine load as displayed in Figure 12(C) and the highest engine speed. However, the lowest CO_2 emission occurred at a lower engine load, whereas the engine load had no significant effect on the CO_2 emissions as presented in Figure 12 (D). Figure 12 (E) shows that the minimum value of the ISFC is indicated at the maximum value of engine load and speed.

Overall, it can be concluded that the load has a major parameter impact on all output responses based on the results and statistical analyses. The engine speed has less impact on the output response from the engine load. The used type fuel was less important on power while the ISFC response had the highest impact of fuel.

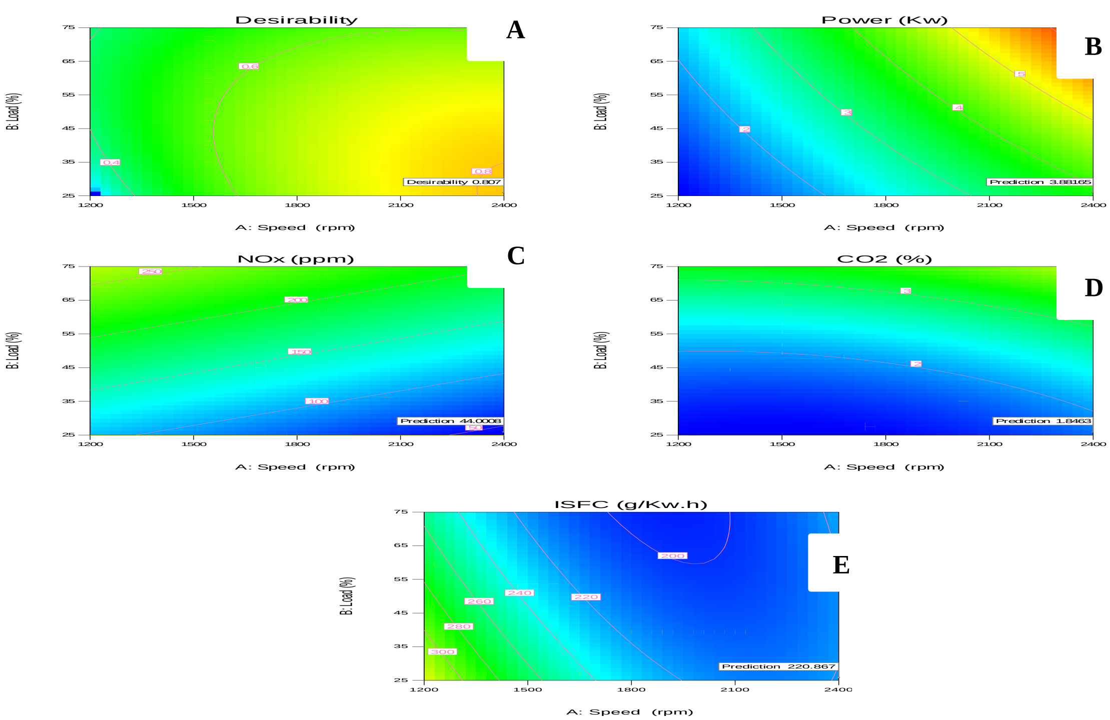

Figure 12. Counter Plots of speeds and loads; (A) desirability, (B) power, (C) NOx emission, (D) CO_2 emissions and *(*E) ISFC.

CONCLUSION

The emissions and performance of single cylinder compression ignition engine fuelled with fusel oil-diesel blends and diesel were analysed using RSM. RSM was applied to examine the performance and emissions of single cylinder CI engine running on fusel oil-diesel blends and diesel. The goal of this research is to statistically research the impacts of oil-diesel fusel blends on the performance and the exhaust emissions of compression ignition engine and compare it with that of pure diesel fuel. The optimum parameter was selected to minimize the ISFC, NO_x, CO_2 emissions and maximize the power. The following assumptions can be derived from the findings of this investigation:

- Analysis by ANOVA revealed that all models were statistically important.
- The blended fuel F20 has irrelevant impacts on the IP thereby the 20% percentage of fusel oil with diesel may be an acceptable ratio in CI engines in terms of power as well as lowest in NOx emissions with F20. Meanwhile, the highest values of ISFC and CO2 emissions were with F20.
- The best solution was with diesel at the highest speed and medium engine load; and for F20 is solution number 11 with a higher engine speed of 2384.697 rpm.
- The best condition of parameters with diesel compared to F20 was 29.4% for load and 2399 rpm engine speed. Similarly, the anticipated values were 4.06 KW, 220.07 g/KWh, 55.56 ppm and 1.93% for power, ISFC, NOx and CO_2 emissions respectively.
- Mathematical models utilized in this study also allow users to perform predictions for unexperimented factor levels.
- Fusel oil blend with diesel can be regarded as a new encouraged alternative biofuel.

This experimental design and analysis of ANOVA significantly evaluated fusel oil in CI as an alternate fuel. Using different fusel oil blends on particulate matter (PM), this study has raised numerous issues that need further research for example the effects of higher compression ratio or ignition timing.

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