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A RSM based Grey Relation Analysis of Process Parameters in a CI Engine using Various Bio Diesel Blends

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This work exhibits the performance output and emission results of Undi bio diesel with butanol blend in a CI engine at varying load conditions. In this work two butanol blends has been exploited for the experiment along with Undi bio diesel and diesel. The other blend contained 50% Undi also 50% diesel and compared with base fuel diesel. From the experimental results it was found that blend containing 50% Undi bio diesel and 50% diesel displayed better results for BThE, bsfc and UHC among all the blends where as lower NO_x was obtained for the butanol blends. After that Grey relation analysis based RSM was executed in the work to see the significance of the experimental results through GRA and validation of the work was executed which resulted adequate response.

Keywords: Bio diesel, CIEngine, Undi, Butanol, GRG, RSM.

Introduction

Alternative fuels have gained fruitful interest and very respectable growth as an substitute of fossil fuels[1], which are used in the field of energy, also exerted in various industries, transport system and automotives[2]. This interest in alternative fuels took place due to rapid decreasing of the fossil fuel quantity and also due to the harmful effects causing from the fuels emissions worldwide[3]. And therefore from past years the use of alternate source of fossil fuel is receiving more interests. Bio diesels are getting more attention as substitute of fossil fuels due to their sustainability. They are renewable and not harmful for environment[2,4]. Also superior combustion of fuel can be achieved since the higher oxygenated property of the bio diesels than the fossil fuels[4]. In this work three blends of Undi bio diesel was used for the experiment where butanol was used with bio diesel and diesel in two blends (Undi10% Butanol 10% Diesel 80% and Undi 20% Butanol 20% Diesel 60%) and in the third blend Undi and Diesel was used at 50% each.

Materials and methods

In this experiment, the bio diesel used was Undi bio diesel along with butanol, which was used as an additive. The bio diesel used was found from the literature survey where various works were carried out on the bio diesel and its blends. Among them Nanthagopal *et al*. a[5] studied the different portion of diethyl ether in CI engine with calophyllum Inophyllum bio diesel at various percentages of di ethyl ether in diesel-biodiesel blends. The results showed that BThE was lower where as *bsfc* was higher with addition of 12.5% diethyl ether. UHC,CO and NO_x was reduced. Balaji & Cheralathan[6] worked on neem bio diesel with p-phenylenediamene additive in a CI engine where UHC and NO_x was reduced with the use of the additive in the bio diesel blends. Kumar *et al*[7] worked on the Jatropha bio diesel of different blends. From the results it was concluded BThE and *bsfc* was better for B40 blend where as the blends had satisfying results for CO but for NO_x the results were on the higher side. Nanthgopal *et al*. b[8] experimented Calophyllum Inophyllum bio diesel with 1-pentanol and 1-butanol additive in a CI engine. From the result it was found that the higher alcohol blends showed less BThE and higher *bsfc* but the NO_x was lower with the higher alcohol percentages in the blend. Similarly UHC, CO and smoke emission also decreased with the blends having higher alcohol percentage. Dhanamurugan and Subramanian[9] investigated the impact of output characteristics in a CI engine running by Bael bio diesel where they found 80% diesel and 20% bio diesel had the best

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results at 22° bTDC. How *et al*[10] studied the effect of the calophyllum Inophyllum bio diesel in a turbocharged CRDI engine at varying torque and speeds. The results showed less BThE and high *bsfc* for the bio diesel blends. But improved results of CO, smoke and PM emission was obtained whereas NO_x was also higher for the blends. The literature analysis detected that Undi has a broad possibility as a bio diesel in near future in India due to its availability and work has been carried out on the bio diesel along with blends showing good prospective in CI engine. In some works Undi is used with diesel, also in some works it is used with various additives. Butanol and other higher alcohols have superior miscible property with diesel and bio diesel, also can reduce CO,UHC and NO_x emissions which is mentioned in various studies. Butanol is used with this bio diesel at varying blend ratios in a study but with bio diesel diesel and butanol it is less used in CI engine. Transesterfication process was used to reduce the density and viscosity of the vegetable oil since these properties can resist the blends in mixing and can affect the engine and pure bio diesel was obtained from the process. The biodiesel blends used in the work were D100 containing 100% Diesel, Blend 1 containing Bio diesel 10%, Butnol 10% and Diesel 80% , Blend 2 containing 20% Bio diesel, 20% Butanol and 60% Diesel, Blend 3 containing Bio diesel 50% and Diesel 50% .

The properties of the fuels operated during the work are given in Table 1.

Table 1 — Properties of the fuels used

Fuel property	Diesel	Blend 1	Blend 2	Blend 3
Density kg/m^3	850	848.6	847.2	863.5
Viscosity mm^2/s	2.7	2.84	~3	3.61
Calorific value MJ/kg	42	41.06	40.13	~42
Cetane Number	47	46.5	46	51
Oxygen Content	>0.6	3.48	6.66	5.58

A four stroke kirloskar DI engine was operated for the experiments which consists of a single cylinder, where at 1500rpm the loads were varied from (3kg) 25% to (12kg) 100%. The engine was specified by injection pressure of 200bar, compression ratio of 17.5:1 at maximum load of 12kg producing 3.5 kW power. In this engine BThE, *bsfc* were the measured performance parameters, taken from Data Acquisition System. For measuring the emission parameter, AVL DI GAS analyzer was used for UHC and NO_x. The results were calculated at four different loads such as 25% load (3kg), 50% load (6kg), 75% load(9kg) and 100% load (12kg).

Results and Discussion

The results obtained from the experiment were listed in the results and discussion. In the work, BThE, *bsfc* were measured for performance where as UHC and NO_x were measured for emission output. The figure1 (a), (b) and (c) shows BThE, UHC and NO_x results respectively.

Experimental results of *bsfc*

It was found that at overall loads *bsfc* resulted less for diesel than the blends at all loads. The reason behind this was the calorific value, which was higher for diesel. Since diesel has higher calorific value therefore it consumes less amount of fuel for the same output compared to the other blends. For the similar reason of lower calorific value of the blends, the engine required more fuel supply for the output. Similar results were noticed in some studies[5,8]. The *bsfc* was 10.32%, 12.58% and 8.7% less for the Blend1, Blend 2 and Blend 3 respectively at 100% load.

Experimental results of Brake Thermal Efficiency

The figure1(a) measures the result of BThE with increasing load. The diesel resulted better BThE than the blends. The calorific value of diesel was higher,

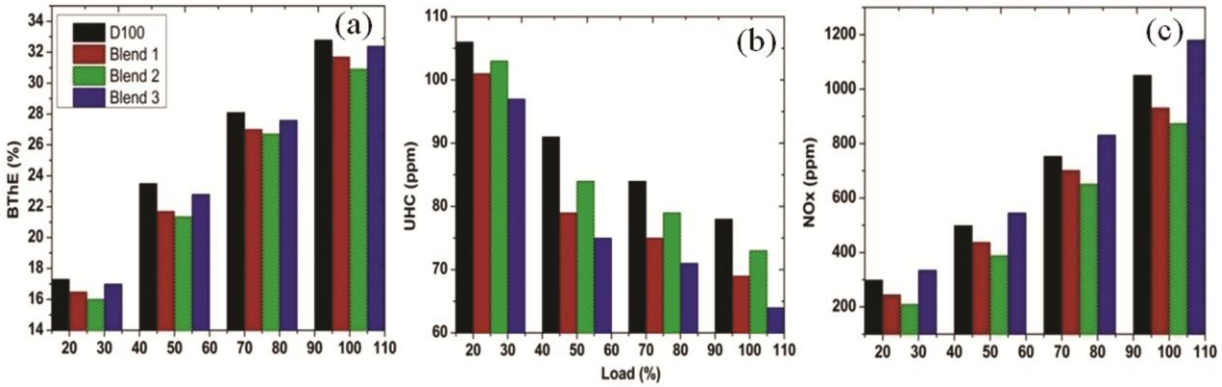

Fig. 1 — (a), (b) and (c) represents the results of BThE, UHC and NO_x at varying loads for the used blends

which was seen in the table 1 compared to the biodiesel diesel and butanol blends as well as diesel and bio diesel blend, which resulted superior burning and heat release during combustion of the fuel inside cylinder leading to higher BThE[8]. BThE resulted 3.35% lower for Blend 1, 5.79% lower for Blend 2 and 1.21% lower for Blend 3 compared to diesel at full load.

Experimental results of Unburnt Hydrocarbon

The figure1(b) represents the results of UHC with varying loads. From the figure it was found that diesel had higher UHC emissions compared to the blends. Since the blends used in this work were more oxygenated fuels compared to diesel hence the combustion resulted for the blends were better than using diesel and reducing UHC[5,11]. The experimental results showed that UHC emission was 11.39%, 6.32% and 17.72% lower for Blend 1, Blend2, Blend 3 respectively compared to diesel.

Experimental results of NO_x

The figure1(c) displays the NO_x results with load variation. In this work higher NO_x was found for Blend 3 compared to diesel. The higher oxygen content of the blend enhancing combustion resulting higher cylinder temperature[8]. But bio diesel butanol blends showed lesser NO_x emission compared to the diesel. Butanol has higher heat of evaporation resulting cooling effect during combustion[8,11] .This interms tends to reduce the temperature inside the cylinder which reduces NO_x with butanol blends. From the results Blend 1 resulted 11.41% less NO_x whereas Blend 2 resulted 16.93% less No_x. But NO_x resulted 12.27% more for Blend 3 compared to diesel at full load conditions.

Grey Relation Analysis

In GRA method to analyze the output data, the data set is first converted in to same scale of 0 to 1 by normalization method known as grey relation generation[12]. For generation of GRA two equations were used for the normalization. Lower the better was used for *bsfc*, UHC, NO_x, whereas Higher the better was used for BThE. The equations for the normalization are mentioned in equation (1)[12]. Calculation of grey relation coefficient was done with deviation and the equation used for this method is mentioned in equation (2 & 3)[12]. Based on that, the Grey relation grade was calculated and the equation used for calculating the values were obtained from the equation no (4)[12]. On the basis of the highest value, the ranks were obtained from GRG shown in Table 2. The GRG based ranking showed test no 16 i.e. A_4B_4 was the optimum process parameter. The response table for GRG was then evaluated from the GRG values. Four levels for each input parameters were calculated and the obtained are shown in Table 2.

Table 2 — Represents the calculated Grey relation grade table for the process parameter and the response GRG for the obtained levels

Test No.	Normalized values				Grey Relation Coefficient				Grey relation Grade	Rank
	BThE	bsfc	UHC	NO_x	BThE	bsfc	UHC	NO_x		
1	0.077	0.293	0.000	0.907	0.351	0.414	0.333	0.844	0.486	15
2	0.446	0.517	0.357	0.701	0.475	0.509	0.438	0.626	0.512	12
3	0.720	0.772	0.524	0.440	0.641	0.686	0.512	0.472	0.578	7
4	1.000	1.000	0.667	0.133	1.000	1.000	0.600	0.366	0.741	3
5	0.029	0.086	0.119	0.964	0.340	0.354	0.362	0.933	0.497	14
6	0.339	0.379	0.643	0.765	0.431	0.446	0.583	0.680	0.535	10
7	0.655	0.690	0.738	0.493	0.592	0.617	0.656	0.497	0.590	6
8	0.935	0.953	0.881	0.256	0.884	0.913	0.808	0.402	0.752	2
9	0.000	0.000	0.071	1.000	0.333	0.333	0.350	1.000	0.504	13
10	0.318	0.341	0.524	0.816	0.423	0.431	0.512	0.731	0.524	11
11	0.637	0.664	0.643	0.545	0.579	0.598	0.583	0.523	0.571	8
12	0.887	0.922	0.786	0.316	0.816	0.866	0.700	0.422	0.701	4
13	0.060	0.228	0.214	0.870	0.347	0.393	0.389	0.794	0.481	16
14	0.405	0.409	0.738	0.654	0.457	0.458	0.656	0.591	0.541	9
15	0.690	0.737	0.833	0.359	0.618	0.655	0.750	0.438	0.615	5
16	0.976	0.974	1.000	0.000	0.955	0.951	1.000	0.333	0.810	1

response GRG for the obtained levels

Symbol	Parameter	Level 1	Level 2	Level 3	Level 4	Max-Min(Delta)	Rank	GRG Mean	Estimated GRG
A	Load	0.5792	0.5935	0.575	0.612	0.037	2	0.5899	0.7731
B	Blend	0.492	0.528	0.5885	0.751	0.259	1		

Table 3 — ANOVA results obtained from RSM for the process parameters

	Model	Linear	Blend	Load	Square	Blend* Blend	Load* Load	2-Way interacton	Blend* Load	Error	Total
DF	5	2	1	1	2	1	1	1	1	10	15
Contribution(%)	95.88	85.51	0.75	84.76	9.97	0.31	9.67	0.39	0.39	4.12	100
Adj SS	0.158683	0.141529	0.001248	0.140281	0.016508	0.000506	0.016002	0.000645	0.000645	0.006821	
F-Value	46.53	103.75	1.83	205.67	12.10	0.74	23.46	0.95	0.95		
P-Value	0.000	0.000	0.206	0.000	0.002	0.409	0.001	0.354	0.354		

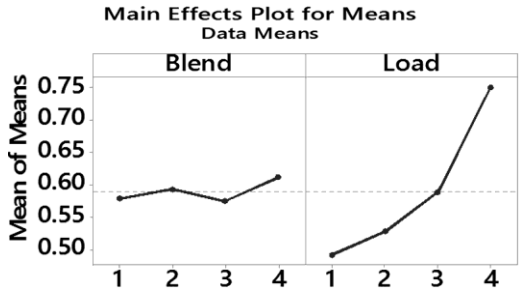

Fig. 2 — represents the Mean output of the optimum process parameter obtained from RSM

Table 2 represents the calculated Grey relation grade table for the process parameter and the response GRG for the obtained levels. ANOVA based RSM analysis was implemented in the work to see the statistical variation from Grey relation analysis. From RSM it was found that the mean of means graph also resulted A_4B_4 as the optimal process parameter shown in Figure 2, similar to the results obtained from GRG table.

R^2 value was 95.88% obtained from RSM which signifies the model accuracy[11]. In the model load (84.76%) showed greater impact of contribution than blend. For confirmation of the predicted optimum condition, estimated GRG was calculated from equation(6)[12] & GRG was found to be 0.7731. In Table 2, the optimum GRG was obtained as 0.81, ranked 1 in the GRG results. The deviation of results was found to be 4.55%, which is very much significant. The confidence interval(CI) was calculated for the validation which was mentioned in equation (7)[12]. The value of CI was obtained in the range of 0.8858 to 0.6606. And from the GRG table the highest ranked value was obtained as 0.81 which showed that the optimum process parameter was cabalistic associated to the statistical model analyzed by RSM.

Conclusion

Undi bio diesel at various percentages was used in this work with butanol blends at varying loads for experimental run. The results obtained from the experiment was directly implemented for grey relation analysis and RSM based ANOVA method was executed for the best GRA result and the obtained result was then validated. The general findings from the work are mentioned below:

- The BThE and *bsfc* showed more significant results for the Blend 3 i.e. Undi bio diesel 50% and Diesel 50% among all the blends.
- UHC emission was lower for all the bio diesel blends at higher loads but NO_x was significantly reduced for bio diesel butanol and diesel blends.
- GRA was implemented in the work for finding the optimal experimental run from the 16 runs using grey grade co efficient.
- For predicting the optimum GRA, RSM method was utilized resulting adequate responses, where validation results showed fruitful results.

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