RSM Based Prediction of Engine Performance and Exhaust Temperature Fuelled with Preheated Cotton Seed Methyl Ester

Shekasa L Nadaf[1], Gurushanth B Vaggar[2*], Farukh Ahmed M H[3], Vishalagoud S Patil[4], Deepak Kothari[5], Praveen K C[5], S C Kamate[6].

[1]*Associate Professor, Department of Mechanical Engineering, Government Engineering College, Talkal, Koppal, Karnataka, India.*

[2*]*Associate Professor, Department of Mechanical Engineering, Alvas's Institute of Engineering and Technology, Mijar, Moodbidri, Karnataka, India.*

[3]*Associate Professor, Department of Mechanical Engineering, Government Engineering College, Huvin Hadagali, Karnataka, India.*

[4]*Assistant Professor, Department of Mechanical Engineering, Government Engineering College, Talkal, Koppal, Karnataka, India.*

[5]*Assistant Professor, Department of Mechanical Engineering, Alvas's Institute of Engineering and Technology, Mijar, Moodbidri, Karnataka, India.*

[6]*Professor and Principal, Hirasugar Institute of Technology, Nidasoshi, Belagavi district, Karnataka, India.*

Abstract: - The conventional fuels are major sources of energy in the world. However, their limited reserves are a great concern owing to fast depletion due to increased demand worldwide. The biodiesel is gaining more importance as an alternative fuel and may be used in 100%, but it requires engine modifications to avoid viscosity problems. The preheating is done to overcome this difficulty. RSM is vital in the solution of many types of problems. This work aims to study the effect of engine torque and the preheat temperature on the usage of cotton seed methyl ester (COME) blends on engine performance and exhaust gas temperature (EGT) with response surface methodology. The interaction curves indicate the increased preheat of higher COME blends shows increased BTE. Further, the highest BTE was observed at 60ºC preheat temperature. From the extensive experimentation with RSM, the tedious experimental work was reduced and the preheated lower COME blends were marginally found better in terms of performance and lower EGT.

Keywords*: RSM, Prediction, Engine Performance, Exhaust gas temperature, Preheat, COME.*

1. Introduction

The fossil fuels are the reason for atmospheric pollution. Hence efforts are being to find alternative sources. Renewable vegetable oils can be used in engines with little or no modification. Thus, lots of efforts are directed at finding fuels as direct substitutes to diesel fuel. The cotton plant is a shrub native to tropical and subtropical regions of the world. The Figure 1a) -1d) illustrates the flower, seed and COME.

1.1 Preheated Vegetable Oil and Their Derivatives

Heated bio-fuel is thinner and makes it easier for the injector pump to deliver fuel to the engine. There is a short time available for the mixing, vaporization and distribution where the vaporization is controlled by the temperature. The ignition lag therefore decreases with increases in the temperature. The ignition limits are wider at increased temperatures because of higher rates of reaction and higher diffusivity coefficient of the mixtures.

Figure. 1 (a) Cotton plant (b) Cotton flower (c) Cotton seed (d) Cotton oil

Murat et al [1] worked on the behaviour of COME-fueled engines. The results show that the preheating up to 90°C led to better effects on power and emissions. Siva Kumar et al [2] studied the engine fuelled with blends of biodiesel from COME at various load conditions. The BTE with biodiesel was lower than that of diesel fuel due to lower heating value. Rao et al [3] investigated biodiesel blends which resulted in a slightly increased BTE. The EGT decreased with the COME as compared to diesel. Anbarasu et al [4] indicated that the preheated COME (up to 80°C) improved BTE and reduced CO and HC emissions. The experimental matrix was created using RSM with 3 inputs and 3 responses. The experiments were performed as per the RSM matrix with varied load, blend and preheat temperature. The most important performance parameters analyzed were BTE, BSFC, and EGT. Dilip Kumar & Ravindra Kumar [5] studied the blends of COME and the results revealed that an increase in BTE was obtained for B20. The smoke and emissions for the blends were less as compared to diesel. Bhojrai Kale et al [6] and Sandeep Singh et al [7] studied the performance of engines using COME and the results revealed that BTE was greater in comparison with diesel. Choudhury et al. [8] and Vijay Chauhan [9] preheated the vegetable oil up to 90°C to obtain the lower oil viscosity. The emission of HC, CO_2, and NO_2 was found to be significantly closer compared to diesel. Ingle et al. [10] compared unheated and preheated COME and results revealed that preheating up to 90° C led to increased BTE and BSFC.

1.2 Response Surface Methodology (RSM):

RSM is an efficient technique for process optimization. In case of availability of complex variable systems, conducting many experiments would be time-consuming and expensive. It is required to have a well-designed experimentation plan to capture more details from lesser experiments. RSM is a statistical and mathematical tool helpful in analyzing, modelling, optimizing, and determining the interactions among the different variables and responses. The RSM tasks to build models evaluate the effects of variables and establish the optimal performance conditions by experimental design and regression analysis.

1.2.1 The experimental matrix using RSM

With the presence of complex variables available in experiments, conduction would take much time and be costly. It is required to have a designed experimental plan to get more information from less number of experiments (one factor at a time).

1.2.2 Design of experiments (CCD):

The experimental design expert trial version-9 software is used to conduct statistical analysis and to develop mathematical models. The experiments were designed according to Central Composite Design (CCD). The factors and their levels used in this work are shown in Table 1. The experimental plan with the process parameter levels and experimental results are shown in Tables 1 and 2.

1.2.3 Empirical Modelling by RSM:

The input parameters like applied torque; blended with preheated temperature that affect the engine behavior are identified from the literature. The variables are set at 3 levels and presented in Table 1, with 5 points and 3 replication points utilizing RSM. The total experimental runs are 40 as in Table 2. The experiments were conducted before the plan and the data collected was loaded into the software.

Table 1: Considered factors for diesel engine performance test and their levels.

Parameters	Levels				
	-1.62	-1	0	1	1.68
Loads	2	4.84	9	13.16	16
Blends	30	45	65	85	100
Preheated temperature °C	40	45	50	55	60

Table 2: Thermo-physical properties of blends of COME.

Sl. No	Properties	Units	Diesel	B30 COME	B45 COME	B65 COME	B85 COME	B100 COME
1	Kinematic viscosity @ 40°C	centi-stoke	2.83	3.4226	3.8959	4.2695	4.863	6.0
2	Density	Kg/m³	865	854	866	882	898	895.700
3	Calorific value	kJ/kg	42588	41890	40330	39610	38440	39600
4	Flash point	ºC	62	81	98	121	143	110
5	Fire point	ºC	68	86	103	125.6	148	173

2. Experimental Setup:

The experimental set-up of the work with various instrumentation components is shown in Figure 2. It consists of AV1 Kirloskar, single cylinder, 4-stroke, diesel engine of 3.7 Kw rated power.

a)

b)

Figure 2: (a) Experimental test rig of computerized diesel engine b) Data acquisition system

3. Results and Discussions

The scheme of doing experiments has been selected & the experiments were done to record the response of process variables. The study of data has been done in 2 phases. The 1st phase is concerned with ANOVA and effect of the all factors and interactions. The 2nd phase is to get the correlations between parameters by regression equations. The experiment plan consists of 40 tests. The responses studied are the BTE, BSFC and EGT. The CCD to obtain BTE, BSFC and EGT are observed in Table 3.

Table 3: Experimental data.

Std	Run	Block	A:Torque	B: Blend	C:Preheat	BTE	BSFC	EGT
29	1	Block 1	9.00	65.00	50.00	0.17	0.48	101.85
11	2	Block 1	13.16	44.19	55.95	0.17	0.476562	122.77
28	3	Block 1	9.00	65.00	60.00	0.178	0.509237	115.1
38	4	Block 1	9.00	65.00	50.00	0.17	0.48	101.85
27	5	Block 1	9.00	65.00	60.00	0.17	0.527946	112.05
35	6	Block 1	9.00	65.00	50.00	0.172151	0.4872	101.85
6	7	Block 1	4.84	85.81	44.05	0.21	0.77	92.31
16	8	Block 1	13.16	85.81	55.95	0.152629	0.356121	114.85
23	9	Block 1	9.00	100	50.00	0.19	0.495997	83.74
1	10	Block 1	4.84	44.19	44.05	0.179968	0.688966	121
14	11	Block 1	4.84	85.81	55.95	0.1812	0.66178	105.69
20	12	Block 1	16.00	65.00	50.00	0.16336	0.465868	128.96
33	13	Block 1	9.00	65.00	50.00	0.1709	0.482774	101.85
40	14	Block 1	9.00	65.00	50.00	0.170732	0.482106	101.85
7	15	Block 1	13.16	85.81	44.05	0.211833	0.393923	98.39
37	16	Block 1	9.00	65.00	50.00	0.170721	0.48	101.85
39	17	Block 1	9.00	65.00	50.00	0.175407	0.477179	101.85
31	18	Block 1	9.00	65.00	50.00	0.170465	0.475844	101.85
8	19	Block 1	13.16	85.81	44.05	0.196813	0.466293	98.39
22	20	Block 1	9.00	30.00	50.00	0.184304	0.497598	119.5
18	21	Block 1	2.00	65.00	50.00	0.18265	1.07	118.4
30	22	Block 1	9.00	65.00	50.00	0.172529	0.48	101.85
26	23	Block 1	9.00	65.00	40.00	0.179442	0.488116	113.52
32	24	Block 1	9.00	65.00	50.00	0.176198	0.48	101.85
3	25	Block 1	13.16	44.19	44.05	0.183978	0.38	129.5
25	26	Block 1	9.00	65.00	40.00	0.190934	0.437218	113.52
17	27	Block 1	2.00	65.00	50.00	0.197874	1.04	121.8
34	28	Block 1	9.00	65.00	50.00	0.167	0.48	101.85
13	29	Block 1	4.84	85.81	55.95	0.189238	0.7	105.69
4	30	Block 1	13.16	44.19	44.05	0.17	0.373423	124.65
5	31	Block 1	4.84	85.81	44.05	0.21	0.827101	89.8
24	32	Block 1	9.00	100	50.00	0.19147	0.523848	83.74
10	33	Block 1	4.84	44.19	55.95	0.19	0.738471	123.7
36	34	Block 1	9.00	65.00	50.00	0.173073	0.48	101.85
2	35	Block 1	4.84	44.19	44.05	0.175506	0.675409	122.2
12	36	Block 1	13.16	44.19	55.95	0.172162	0.46118	122.77
21	37	Block 1	9.00	30.00	50.00	0.186347	0.488058	121.33
19	38	Block 1	16.00	65.00	50.00	0.16622	0.489626	128.96
9	39	Block 1	4.84	44.19	55.95	0.231	0.718	124.67
15	40	Block 1	13.16	85.81	55.95	0.15427	0.447602	114.85

3.1 Checking data & adequacy of empirical relationships of model.

3.1.1Normality of data

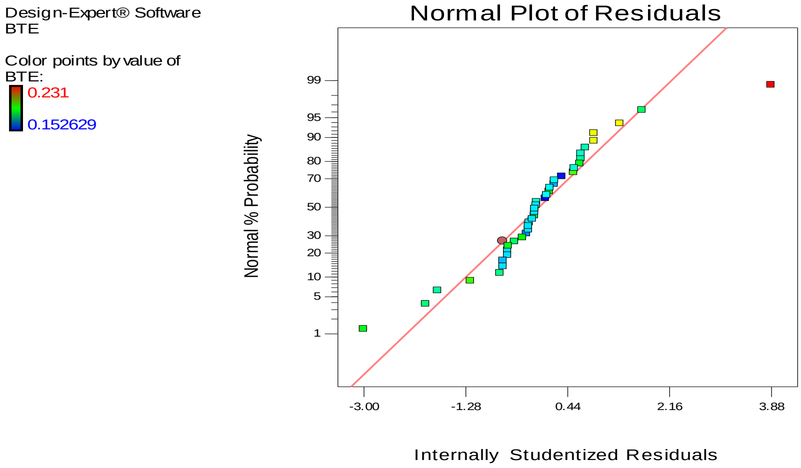

Figure 3: Normal probability plot for BTE.

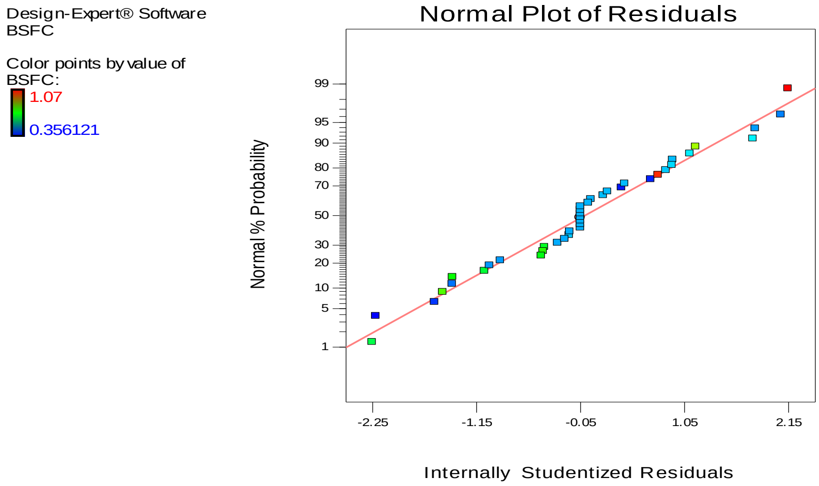

Figure 4: Normal probability plot for BSFC.

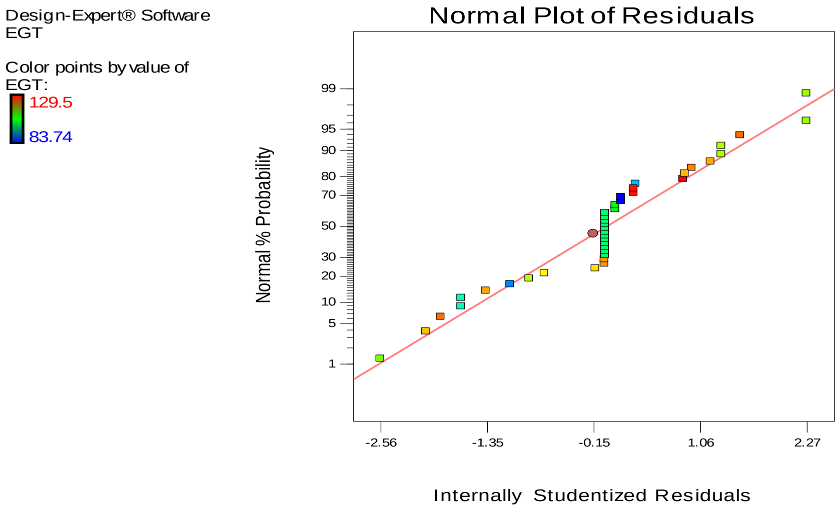

Figure 5: Normal probability graph for EGT.

The data normality was checked by normal probability graph. Figure 3 to 5 illustrates residual plots for BTE, BSFC and EGT. The results showed that residuals are falling on a straight line. That shows normally distributed errors.

3.1.2 Independency of the data

The independencies of the obtained data were seen by drawing a graph for residuals and the run order. The plots for BTE, BSFC and EGT are indicated in Figures 6 to 8. It's illustrated, that no predictable pattern is seen because all the run residues are between the levels of -3 to 3.

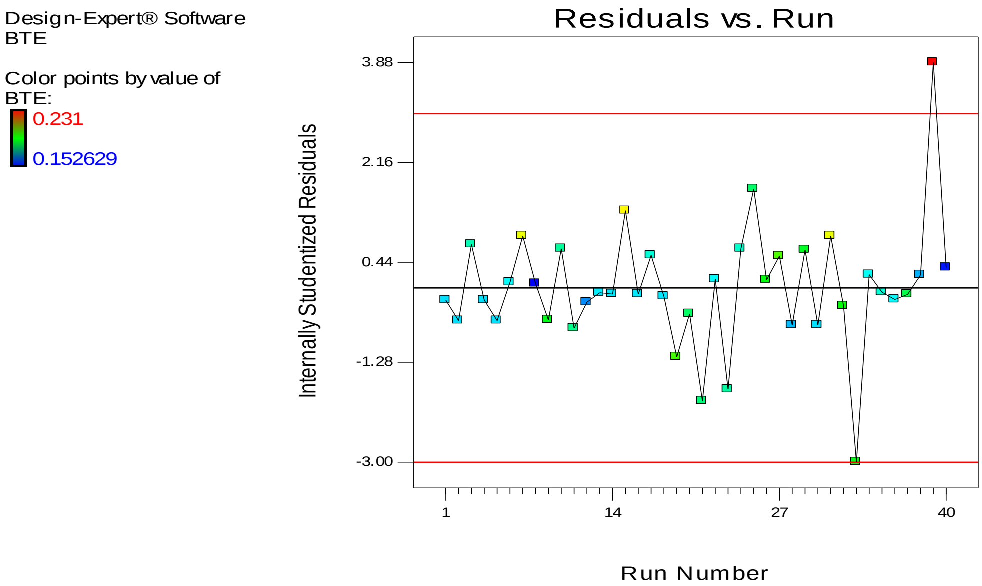

Figure 6: Residual plots for BTE.

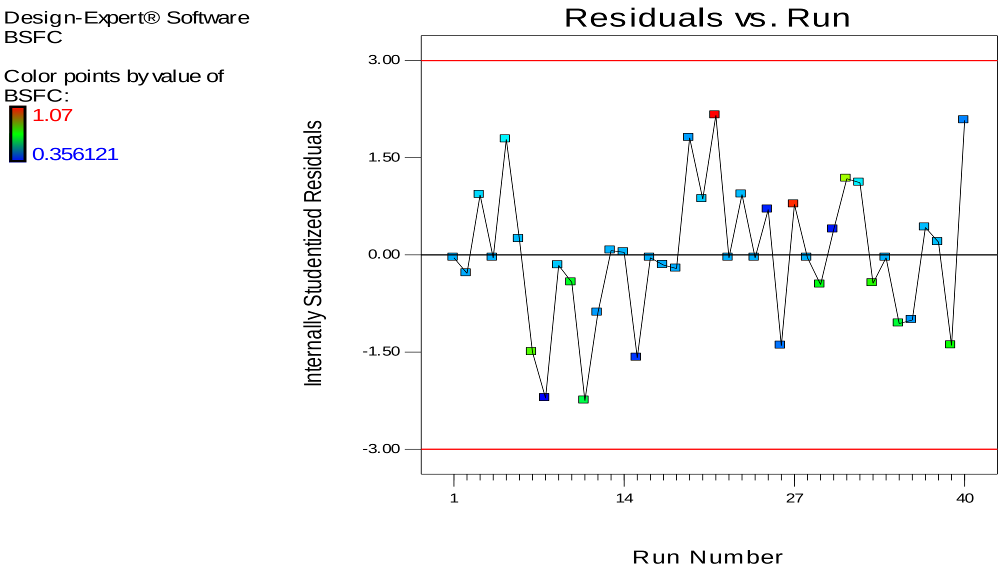

Figure 7: Residual plots for BSFC.

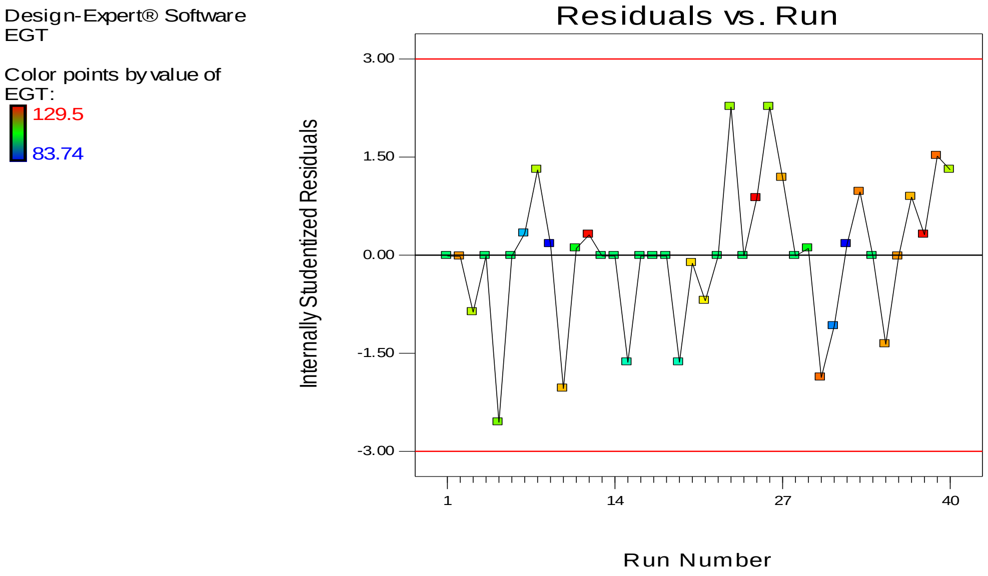

Figure 8: Residual plots for EGT

3.2 Analysis of Variance (ANOVA).

3.2.1 ANOVA for BTE.

Table 4: BTE ANOVA.

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	8.205E-003	9	9.116E-004	17.07	< 0.0001	Significant
A-Torque	*2.125E-003*	*1*	*2.125E-003*	*39.78*	*< 0.0001*	
B-Blend	*9.735E-005*	*1*	*9.735E-005*	*1.82*	*0.1871*	
C-Preheat	*6.695E-004*	*1*	*6.695E-004*	*12.53*	*0.0013*	
AB	*1.850E-006*	*1*	*1.850E-006*	*0.035*	*0.8536*	
AC	*1.049E-003*	*1*	*1.049E-003*	*19.63*	*0.0001*	
BC	*2.627E-003*	*1*	*2.627E-003*	*49.18*	*< 0.0001*	
A^2	*2.431E-004*	*1*	*2.431E-004*	*4.55*	*0.0412*	
B^2	*1.262E-003*	*1*	*1.262E-003*	*23.63*	*< 0.0001*	
C^2	*3.810E-004*	*1*	*3.810E-004*	*7.13*	*0.0121*	
Residual	1.603E-003	30	5.342E-005			
Lack of Fit	*2.159E-004*	*5*	*4.317E-005*	*0.78*	*0.5746*	*not significant*
Pure Error	*1.387E-003*	*25*	*5.547E-005*			

It's seen that, when the value of 'p' is less than 0.05, the model terms are significant. As observed from Table 4, P values of torque and preheat are less than 0.05; Hence, torque & preheat have significant effects on the BTE.

3.2.2 ANOVA for BSFC

Table 5: ANOVA for BSFC.

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	1.00	9	0.11	162.31	< 0.0001	Significant
A-Torque	0.70	1	0.70	1020.19	< 0.0001	
B-Blend	1.037E-003	1	1.037E-003	1.52	0.2278	
C-Preheat	1.092E-003	1	1.092E-003	1.60	0.2162	
AB	1.707E-003	1	1.707E-003	2.49	0.1247	
AC	4.592E-003	1	4.592E-003	6.71	0.0146	
BC	0.020	1	0.020	29.50	< 0.0001	
A2	0.27	1	0.27	392.62	< 0.0001	
B2	2.335E-004	1	2.335E-004	0.34	0.5634	
C2	2.617E-005	1	2.617E-005	0.038	0.8463	
Residual	0.021	30	6.842E-004			
Lack of Fit	8.197E-003	5	1.639E-003	3.32	0.194	Not significant
Pure Error	0.012	25	4.931E-004			
Cor Total	1.02	39				

In this ANOVA study, torque has a remarkable effect on the BSFC. The quadratic term of torque (A× A) is also significant. The interaction of A×C and B×C is insignificant in the model.

3.2.3 ANOVA for EGT.

The ANOVA Table 6 shows that all terms are significant excluding interaction of torque & preheat (A x C). From the F value assessment, it's seen that the predominant factors on the response as per hierarchy are blend, quadratic term (A x A), quadratic term (C x C), the interaction of (BxC), torque and preheat. The interaction effect AX B and B X C also affect EGT.

Table 6: ANOVA for EGT.

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	5905.23	9	656.14	139.58	< 0.0001	Significant
A-Torque	184.10	1	184.10	39.16	< 0.0001	
B-Blend	3178.56	1	3178.56	676.18	< 0.0001	
C-Preheat	127.16	1	127.16	27.05	< 0.0001	
AB	38.66	1	38.66	8.22	0.0075	
AC	6.41	1	6.41	1.36	0.2520	
BC	269.21	1	269.21	57.27	< 0.0001	
A^2	1768.11	1	1768.11	376.14	< 0.0001	
B^2	0.32	1	0.32	0.069	0.7950	
C^2	449.57	1	449.57	95.64	< 0.0001	
Residual	141.02	30	4.70			
Lack of Fit	112.81	5	22.56	20.00	< 0.0601	not significant
Pure Error	28.21	25	1.13			
Cor Total	6046.25	39				

3.3 Regression Analysis

3.3.1 Regression for BTE.

The determination coefficient (R^2) shows the goodness of fit for the model. The predicted R^2 value (64.47%) show good agreement with the adjusted R^2. Lack of fit is not significant for the developed relationships as required (Anoop et al., 2009). Hence, the developed relationships (Equation no.5.1) can be effectively applied to predict the response.

BTE =+0.17-8.820E-003 *A-4.951E-003 *C-8.095E-03* A * C0.013 * B * C+2.904E-003* A^2+6.618E-003* B^2+3.636E-003 * C^2 …………………………..Eqn.1

3.3.2 Regression for BSFC.

The predicted determination coefficient (R^2pred = 0.9560) is in good agreement with the adjusted determination coefficient (R^2adj = 0.9738). These results show the good model capability. Hence, the developed relationships (Equation no.5.2) can be utilized.

BSFC =+0.48-0.1* A +0.017 * A * C-0.036 *B * C+0.097 * A^2………………..Eqn. 2

3.3.3 Regression for EGT.

The ANOVA tests of EGT are recorded in Table 5.4. The value of the adjusted R is 96.97%. The predicted R^2 value (94.95%) also demonstrates a better concord value. The Lack of fit is not significant for the formed relationships as it is required (Anoop et al., 2009). Thus, the developed relationships (Equation no.4.3) can be utilized.

EGT=+101.88+2.60 *A-10.79*B+2.16*C+1.55*A*B+4.10 *B*C+7.83 *A^2-+3.95* C^2 ….Eqn.3

3.4 Main Effect and Interaction Plots

The developed equations can be utilized to predict BTE, BSFC and EGT by putting the required parameters. Using these equations, the main and interaction effects on the BTE, BSFC and EGT are graphed in the form of perturbation plots.

3.4.1 Main Effect and Interaction Plots for BTE.

3.4.1.1 Effect of Torque and preheat on BTE

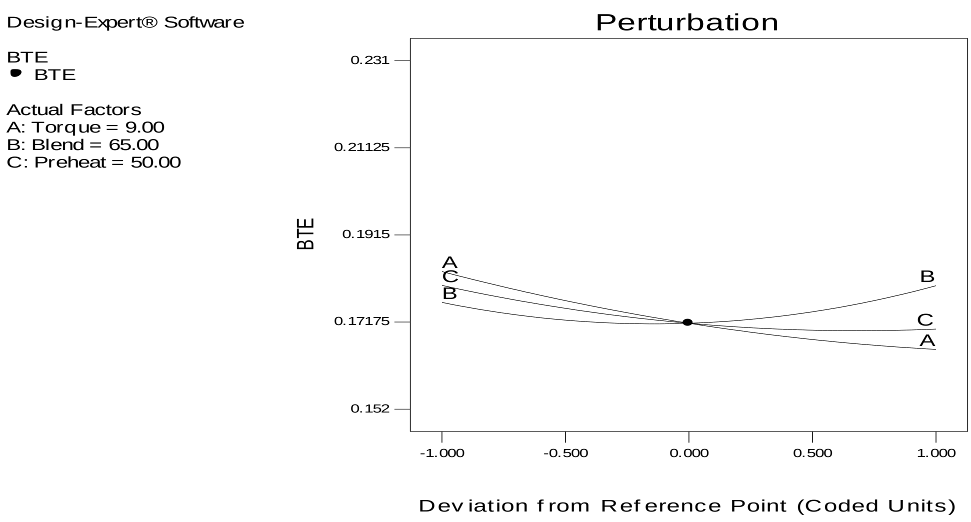

Figure 9: Perturbation plot for BTE

Figure 9 shows the perturbation plot for BTE showing the effects of torque, blend and preheat temperature on engine BTE. The BTE decreased with increased torque from zero to full torque. The lowest BTE of 16.2% was observed at applied full engine torque. The BTE against increasing the preheating temperature of biodiesel blends are plotted in Figure 9. The results indicated that the BTE of the engine decreased with increased preheating temperature from 40 °C to 60 °C. Further, the performance results reported that BTE increased for increased blends.

3.4.1.2 Interaction effect of torque and blend on BTE

The Figure 10 indicates the interaction plot for BTE showing the effects of torque and blend on BTE. The interaction curves shows that the engine exhibit higher BTE for higher blends of COME and lower applied torque. This is because of reduced viscosity of higher COME blends due to preheat.

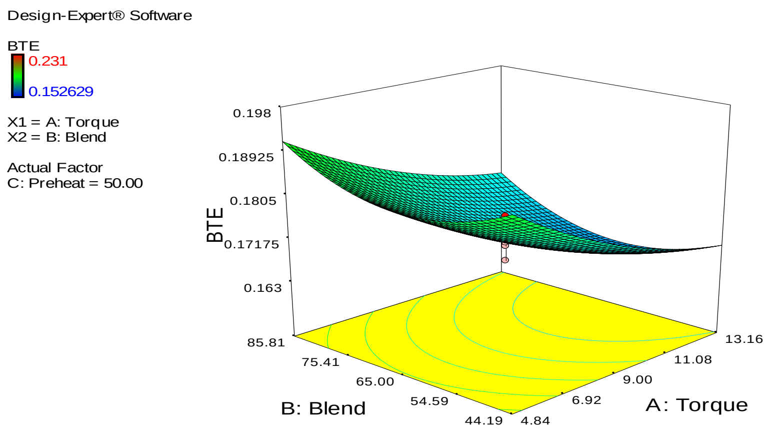

Figure 10: Interaction effect of blend and torque on BTE

3.4.1.3 Interaction effect of blend and preheat on BTE

The Figure 11 indicates the interaction plot for BTE showing the effects of blend and pre-heat temperature of COME blends on BTE of the engine. The interaction curve indicates that the increased preheat temperature of COME blends shows increased BTE for higher blends. Further, the highest BTE observed at 60 ºC preheat temperature. This is mainly due to the reduced viscosity of COME blends due to preheat.

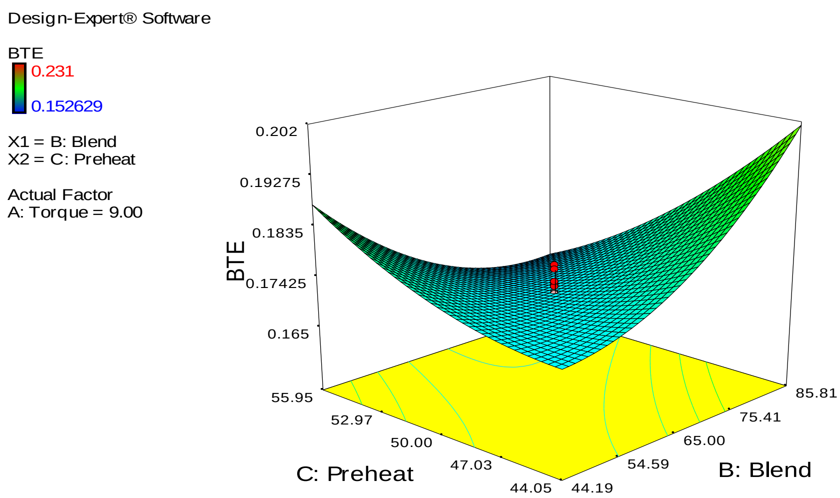

Figure 11: Interaction effect of blend and preheat on EGT

3.4.2 Main Effect and Interaction Plots for BSFC.

The result at Figure 12 presents the value of BSFC at elevated COME blends inlet temperature with varied torque. The increasing torque on the engine, the value of BSFC decreased and the higher situation observed at low torque condition. It also observed that the highest value of BSFC is found for higher blend and higher preheat temperature conditions.

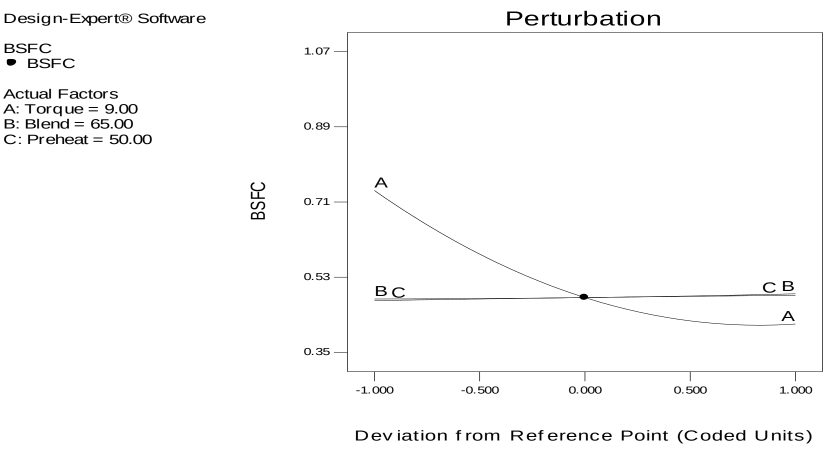

Figure 12: Perturbation plot for BSFC

The trend in Figure 12 shows because of increased torque, the BSFC decreased. This may be because of increased total energy with the increase in torque.

3.4.2.1. Interaction effect of torque and preheat on BSFC

The experiments carried out at increased load conditions in a single cylinder, four stroke, and direct injection diesel engine. Before supplied to the engine, Cotton seed methyl ester (COME) preheated to five different temperatures, namely 40˚C, 45˚C, 50˚C, 55˚C and 60˚C. The results show that preheating COME at 40˚C leads to favorable effects on the BSFC. The interactive effects of preheat temperature and applied engine torque on BSFC is shown in Figure 5.11 Further, it's seen that the BSFC of preheated COME found decreased with increased torque and the higher BSFC observed at higher preheat temperatures. The higher engine torque and lower preheat temperature shows lower desirable BSFC as shown in figure. The preheat temperature seems not strongly influence the BSFC but the torque has influence on the BSFC.

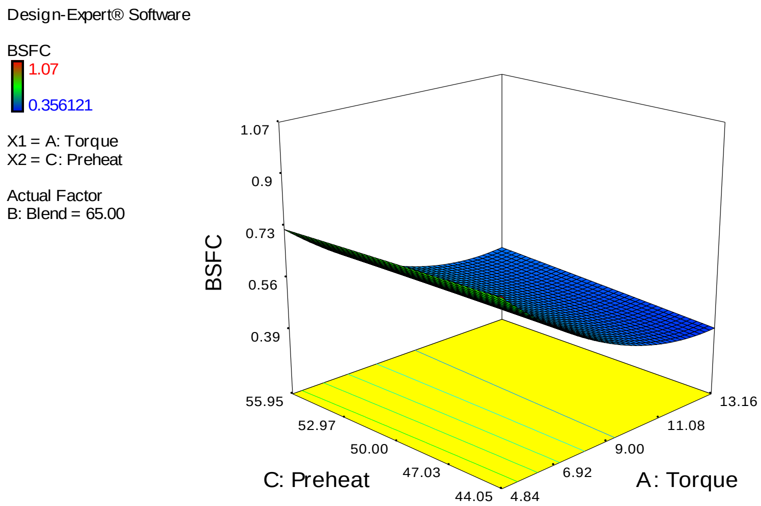

Figure 13: Interaction effect of blend and preheat on EGT

3.4.2.2 Interaction effect of blend and preheat on BSFC

The interactive effects of COME blend and preheat temperature on BSFC is shown in Figure 14. The interactive curves indicate that the lower preheat temperature and the lower COME blend exhibit lower desirable BSFC in comparison with higher blends and higher preheat temperatures. Further, the higher blend and the higher preheat temperature of 65ºC shows higher BSFC.

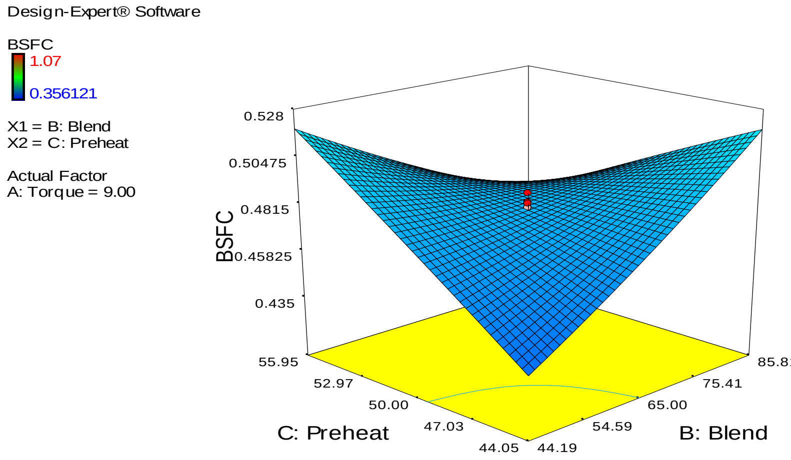

Figure 14: Interaction effect of blend and preheat on EGT

3.4.3. Main Effect and Interaction Plots for EGT

Figure 15 shows the main effect of using preheated COME blends at increased torque on BTE. As per the experimental matrix using RSM the COME blends preheated from 40 ˚C to 60 ˚C and the engine is applied with increased torque from low to full load.

3.4.3.1 Effect of Torque, blend and preheat on EGT

Figures 15 indicate the effect of EGT at increased torque and preheat temperature. The EGT increased because of the poor burning nature and high viscosity of COME blends. The burning qualities were improved with increased diesel in the blend and the increased preheat value. Further, Figure 15 reports that the increased COME concentration in the blend shows decreased EGT due to added preheat. This is due to the higher viscosity leading to lower burning temperature in the engine cylinder and the lower EGT. Figure 15 also shows the effect of COME blends preheat on EGT of the engine. It’s noticed that the increased preheat results increased EGT. This is the cause of increased combustion rate and reduced blend viscosity.

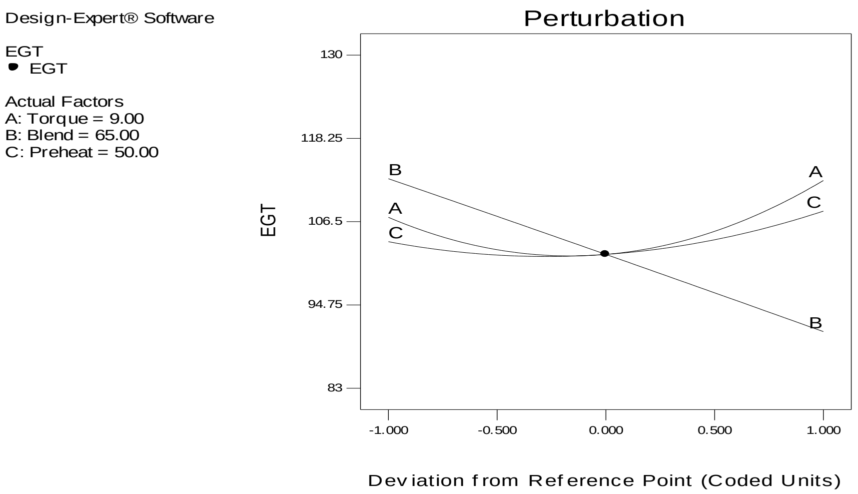

Figure 15: Perturbation plot for EGT

3.4.3.2 Interaction effect of torque and blend on EGT

The Figure 16 shows the interactive effects of engine torque and COME blends on EGT. The engine EGT is one of the most important parameters of engine exhaust, since the engine emissions and pollutants are strongly depending on the engine EGT. The engine EGT increased with increased torque because of increased oil consumption and the larger COME blends exhibit lower EGT due to higher viscosity values.

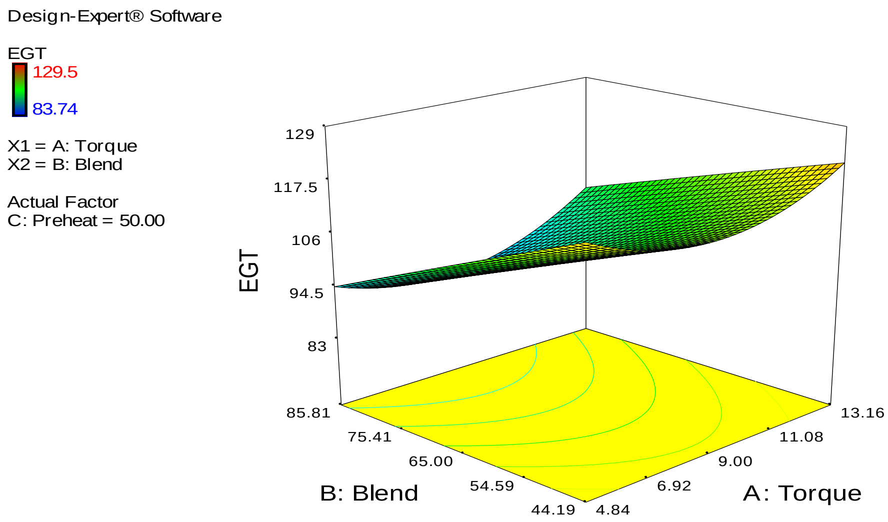

Figure 16: Perturbation plot for EGT.

3.4.3.3 Interaction effect of blend and preheat on EGT

The Figure 17 shows the interactive effects of engine COME blends and preheat temperature on EGT. The curves indicate the reduced EGT with increased COME in the mixture and the higher EGT observed at higher preheat temperature of 60°C. Thus, the higher preheat temperature with lower blend ration results favorable effects in regard to engine behavior.

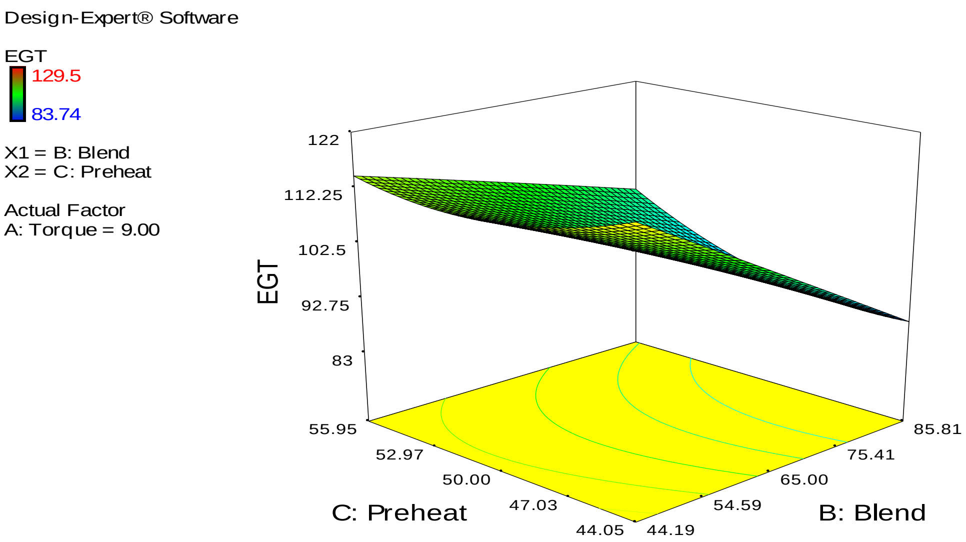

Figure 17: Interaction effect of blend and preheat on EGT.

4. Conclusions

This work aims to study the effect of engine load & preheat temperature on the usage of COME blends on the diesel engine performance and EGT with RSM.

- Experiments were conducted in a single-cylinder, four-stroke computerized diesel engine.
- The experimental matrix for experimental work has been designed using RSM.
- The engine experimented with 40 standard runs with the designed run order using RSM.
- The interaction curve indicates that the increased preheat of higher COME blends shows increased BTE. Further, the highest BTE was observed at 60 ºC preheat temperature.
- The highest value of BSFC was found for higher blend and higher preheat.
- The engine EGT increased with increased torque due to increased fuel consumption and the higher COME blends exhibit lower EGT.
- Thus, the higher preheat temperature with a lower blend ratio result in favourable effects on engine performance and emissions.

From the extensive experimentation with RSM, the tedious experimental work was reduced and the preheated lower COME blends were marginally found better in terms of performance and lower EGT.

References

[1] Karabektas Murat, Gokhan Ergen and Murat Hosoz, The effects of preheated COME on the performance and exhaust emissions of a diesel engine, Applied Thermal Engineering, 2008, Volume 28, Issues 17-18, 2136-2143.

[2] Sivakumar V.R., Gunaraj V and Rajendran P., Statistical analysis on the performance of engine with jatropha oil as an alternate fuel, IJEST, 2010, Vol. 2(12), 7740-7757.

[3] Srinivasa Rao P. N V Talupula and Sudheer Prem Kumar, Multi response optimization of characteristics of HCCI engine using blends of kusum oil biodiesel using Taguchi-GRA-PCA, AIP conference proceedings 2024, Volume 3007, Issue 1.

[4] Anbarasu G, T. Elangovan and L. Jeryrajkumar, Development of Calophyllum inophyllum Biodiesel and Analysis of its Properties at Different Blends, International Journal of ChemTech Research, Vol.9, No.04 pp220-229, 2016.

[5] Dilip Kumar and Ravindra Kumar, Experimental investigation of cottonseed oil and neem Methyl esters as biodiesel on CI engine, IJMER, 2012, VOL-2. Issue-4, pp-1741 – 1746.

[6] Bhojrai Kale and Prayagi, Performance Analysis of Cottonseed Oil Methyl Ester for Compression Ignition Engines, IJETAE, Vol.2 Issue 8, pages 117-120.

[7] Sandeep Singh, Sumeet Sharma, Mohapatra and Kundu, Characteristics of biodiesel derived waste cotton seed oil and mustard oil, Asian Journal of Engineering and Applied Technology, Vol.2 No.2,2013, pp.73-77.

[8] Choudhury S and Bose P. K, Karanja or jatropha–a better option for an alternative fuel in CI engine, International Conference on IC Engines (ICONICE), 2007, Hyderabad.

[9] Vijay Chauhan, A review of research in mechanical engineering on recovery of waste heat in internal combustion engine, International Journal of Research In Engineering & Applied Sciences, 2012, Volume 2, Issue 12, pp 2249-3905.

[10] Ingle. P.B, Ambade R.S., Paropate R.V., Bhansali S.S., Comparisons of diesel performance neat and preheated transesterified cotton seed oil, International Journal of Advanced Engineering Sciences And Technologies, 2011, vol no. 5, issue no. 1, 067 – 071.