Performance Modeling of Refined Corn Oil in Direct Ignition Diesel Engine Using Response Surface Methodology

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Abstract: The focus of this paper is on creating a mathematical modeling for the input parameters of the engine such as injection pressure, injection timing, blend ratio and the output parameter brake thermal efficiency and brake specific fuel consumption. The four stroke direct injection, Kirloskar diesel engine was used to conduct the experiments. The refined corn oil was transesterified with Methanol and Sodium Hydroxide to obtain corn methyl esters. The corn methyl esters were blended with petro diesel in various proportions and used as fuel. The response was predicted using Analysis of Variance (ANOVA). The developed models were analyzed using the R – Squared value.

Key words: DI Diesel engine • Corn methyl esters • RSM and ANOVA

INTRODUCTION

In India, the environment is polluted to an alarming extent due to the exhaust emission from the Internal Combustion engines. In order to reduce the emission and to improve the performance of the diesel engine we look for an alternative fuel. Banapurmath et al., [1] investigated the effects of emission and performance of the Honge methyl esters by varying the compression ratio, injection pressure and the injection timing and developed the second order mathematical model using response surface methodology. Kalamoorthy and Paramasivam et al., [2] reported that using the karanja biodiesel and the varied engine parameters, they could optimize the engine parameters using design of experiments and Taguchi. The results showed that for the compression ratio of 17.7, 20% blend, 230 bar injection pressure, 70% load and the 27° BTDC less emission and better performance could be achieved. Karthikeyan et al., [3] found that the blends of turpentine and diesel gave the optimal values at 40% blend, 29° BTDC and at 180 bar injection pressure and an increase in brake thermal efficiency by 2.5%. Kannan et al., [4] reported that with the use of response surface methodology, the waste cooking oil methyl esters could effectuate the lower emissions and an increase in brake specific fuel consumption and reduction in the brake thermal efficiency at full load condition. Natraj et al., [5] investigated on minimizing the number of experiments using Taguchi method and found the optimal design operating conditions for the diesel engine to reduce emissions. Sunil dhingra et al., [6] used the response surface methodology and the genetic algorithm to improve the yield of the biodiesel. The result showed that the yield was closer to the predicted value. Dairo, [7] optimized the production of castor oil bean-seed oil using response surface method and central composite method. The result showed that the confidence level was 95% and it matched with the ASTM standards. Hemanandh and Narayanan [8] showed that changing the injection pressure at various loadings and using the methyl esters of refined sunflower oil resulted in an increase in CO and NO, and a decrease in HC. Karnwal et al., [9] used the Taguchi and Grey analysis to model and optimize the design parameter of design engine, such as injection timing, compression ratio, nozzle opening and the blends of thumba biodiesel. Puhuan et al., [10] reported that by varying the injection pressure and for the optimum injection pressure of 240 bar, for the high linolenic linseed
oil methyl ester, he could improve the thermal efficiency and reduce the emission. Chauhan et al., [11] used jatropha curcus oil and preheated it to reduce viscosity and fed it into the diesel engine. He found that it resulted in an increase in CO and HC and a decrease in NOx compared with diesel fuel.

**Fuel Preparation:** The refined corn flour methyl esters were prepared by transesterification process. The raw oil was treated with Methanol and the catalyst NaOH was added. The mixture was stirred well for 10 minutes and then heated up to 80°C. The oil turned into orange brown color. The oil was poured into the separator and allowed to cool in room temperature. The methyl esters were separated and washed with distilled water. The methyl esters thus obtained were mixed with diesel in different proportions and used as fuel. The feed and the blends of refined corn oil methyl esters are shown in Figures 1 (a-d).

**Experimental Set-up:** A vertical, 4S kirloskar Direct Injection (DI) diesel engine with single cylinder, compression ratio of 17.5:1, having a constant speed of 1500 rpm was used for the experiment. The injection pressure and the injection timing were varied at different levels. The injection pressure was varied to be 180 bar, 210 bar and 240 bar and the injection timings were to be 21° BTDC, 24° BTDC and 27° BTDC. The emission values were recorded using the AVL 5 gas analyzer and the AVL smoke meter. The details of the test engine and the emission measuring instruments are shown in Table -1 and Table – 2. The experimental set-up is shown in Fig 2.

**Nomenclature:**
- BTE - Brake Thermal Efficiency
- BSFC - Brake Specific Fuel Consumption
- CO - Carbon monoxide
- HC - Hydrocarbon
- NOx - Nitrogen Oxide
- B10 - 10% of Corn Methyl Esters + 90% Petro Diesel fuel
- B25 - 25% of Corn Methyl Esters + 75% Petro Diesel fuel
- B40 - 40% of Corn Methyl Esters + 60% Petro Diesel fuel

**MATERIALS AND METHODS**

The Refined Corn flour oil was procured from the local shop. The Methanol and NaOH were purchased from the suppliers. In phase 1 the corn flour methyl esters were prepared by transesterification process. In Phase 2 the methyl esters were blended with diesel fuel. In phase 3 the fuel was tested in the diesel engine by changing the design parameters and the load.
Table 1: Specification of Test Engine

<table>
<thead>
<tr>
<th>Type</th>
<th>: Kirloskar Vertical, 4S, Single acting, High speed, C.I. Diesel Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion</td>
<td>: Direct Injection</td>
</tr>
<tr>
<td>Rated Power</td>
<td>: 4.3 kW</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>: 1500 rpm</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>: 17.5:1</td>
</tr>
<tr>
<td>Fuel injection pressure</td>
<td>: 210 bar</td>
</tr>
<tr>
<td>Dynomter</td>
<td>: Eddy current</td>
</tr>
</tbody>
</table>

Table 2: Details of Measuring Systems

<table>
<thead>
<tr>
<th>No.</th>
<th>Measurement System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Pressure Transducer GH 12 D</td>
</tr>
<tr>
<td>2.</td>
<td>Software Version V 2.0 - AVL 617 Indimeter</td>
</tr>
<tr>
<td>3.</td>
<td>Data Analyzer from Engine - AVL PIEZO CHARGE AMPLIFIER</td>
</tr>
<tr>
<td>4.</td>
<td>To measure pressure - AVL 364 Angle Encoder</td>
</tr>
<tr>
<td>5.</td>
<td>Smoke meter - AVL 437C Smoke</td>
</tr>
<tr>
<td>6.</td>
<td>5 Gas Analyzer (NO, HC, CO, CO₂, O₂) - AVL DIGAS 444 Analyzer</td>
</tr>
</tbody>
</table>

Table 3: Specifications of Fuel Properties

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cetane Index</td>
<td>51</td>
<td>51</td>
<td>-</td>
<td>35</td>
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<td>2.</td>
<td>Density at 15°C (kg/m³)</td>
<td>820-845</td>
<td>860-900</td>
<td>860-900</td>
<td>923</td>
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<tr>
<td>3.</td>
<td>Kinematic Viscosity at 40 °C cst</td>
<td>2-4.5</td>
<td>2.5-6</td>
<td>1.9-6</td>
<td>5.02</td>
</tr>
<tr>
<td>4.</td>
<td>Flash point°C</td>
<td>35°C</td>
<td>262°C</td>
<td>130°C</td>
<td>162</td>
</tr>
<tr>
<td>5.</td>
<td>Calorific Value, kJ/kg</td>
<td>44,000</td>
<td>-</td>
<td>-</td>
<td>36,824</td>
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</table>

Table 4: Input Parameters

<table>
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<tr>
<th>S.No.</th>
<th>Notation</th>
<th>Parameter</th>
<th>Levels</th>
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<tr>
<td>1.</td>
<td>A</td>
<td>Injection Pressure bar</td>
<td>180</td>
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<td>2.</td>
<td>B</td>
<td>Injection timing deg</td>
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<tr>
<td>3.</td>
<td>C</td>
<td>Blend Percentage (%)</td>
<td>10</td>
</tr>
</tbody>
</table>

The various blends of biodiesel such as B10, B25 and B40 were prepared by volume and their properties are shown in Table -3. The fuel blends were tested in the engine at different injection pressures, injection timings and loads at a constant speed of 1500 rpm. The emissions were recorded and the performances were analyzed.

**RESULTS AND DISCUSSIONS**

**Model Validation:** A quadratic model was developed based on the experimental data. The model was analyzed up to 99% interval using Analysis of Variance (ANOVA). The output parameters of the engine are given in Table – 4. The L₂⁷ orthogonal design matrix is shown in Table – 5. The mathematical regression model was developed based on the experimental data for the refined corn oil methyl esters. The mathematical modelling equation (1) and (2) is as follows:

\[
\begin{align*}
\text{BTE} &= -15.73080 + 0.33550 * A + 1.94667 * B - 0.55751 * C - 2.36111E-003 * A * B - 1.02593E-003 * A * C + 0.023389 * B * C - 5.95062E-004 * A^2 - 0.043210 * B^2 + 4.64938E-003 * C^2 \\
\end{align*}
\]
Table 5: L27 Orthogonal array Design Matrix

<table>
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<tr>
<th>S.No.</th>
<th>STD</th>
<th>Pi bar</th>
<th>Ti deg</th>
<th>Bl %</th>
<th>BTE %</th>
<th>BSFC</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>1</td>
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<td>1</td>
<td>1</td>
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<td>0.059</td>
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<td>1</td>
<td>3</td>
<td>35.56</td>
<td>0.059</td>
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<td>36.78</td>
<td>0.059</td>
</tr>
</tbody>
</table>

Table 6: Analysis of variance table (BTE)

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>p-value</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>28.35008</td>
<td>9</td>
<td>3.150009</td>
<td>1060.049305</td>
<td>&lt; 0.0001</td>
<td>significant</td>
</tr>
<tr>
<td>A-ip</td>
<td>0.125</td>
<td>1</td>
<td>0.125</td>
<td>42.06532498</td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>B-B</td>
<td>0.3042</td>
<td>1</td>
<td>0.3042</td>
<td>102.3701749</td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>C-E</td>
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<td>1</td>
<td>2</td>
<td>673.0451996</td>
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<td>0.658008</td>
<td>221.434675</td>
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<td>AC</td>
<td>2.227408</td>
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<td>2.227408</td>
<td>749.5732432</td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
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<td>BC</td>
<td>14.08333</td>
<td>1</td>
<td>14.08333</td>
<td>4739.359947</td>
<td>&lt; 0.0001</td>
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</tr>
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<td>A^2</td>
<td>1.815</td>
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<td>328.464922</td>
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<td>C^2</td>
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<td>6.161067</td>
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</tr>
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<td>Residual</td>
<td>0.050517</td>
<td>17</td>
<td>0.002972</td>
<td>0.00000</td>
<td>0.00000</td>
<td></td>
</tr>
<tr>
<td>Cor Total</td>
<td>28.4006</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Analysis of variance table (BSFC)

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>9</td>
<td>1.18E-05</td>
<td>280.32</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>A-ip</td>
<td>4.67E-05</td>
<td>1</td>
<td>4.67E-05</td>
<td>1114.05</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>B-B</td>
<td>1.39E-06</td>
<td>1</td>
<td>1.39E-06</td>
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<td>&lt; 0.0001</td>
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<tr>
<td>BC</td>
<td>2.08E-06</td>
<td>1</td>
<td>2.08E-06</td>
<td>49.68</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>A^2</td>
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<tr>
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<td>1</td>
<td>3.63E-06</td>
<td>86.55</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Residual</td>
<td>7.13E-07</td>
<td>17</td>
<td>4.19E-08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cor Total</td>
<td>1.07E-04</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Table 8: Response surface method of evaluation:

<table>
<thead>
<tr>
<th>Model</th>
<th>F- value</th>
<th>Mean</th>
<th>Std. dev.</th>
<th>Model degree</th>
<th>R^2</th>
<th>Adj R^2</th>
<th>Pred R^2</th>
<th>Adeq precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTE</td>
<td>482.34</td>
<td>36.11</td>
<td>0.080</td>
<td>Quadratic</td>
<td>0.9961</td>
<td>0.9940</td>
<td>0.9880</td>
<td>75.079</td>
</tr>
<tr>
<td>BSFC</td>
<td>202.63</td>
<td>0.058</td>
<td>2.514E-004</td>
<td>Quadratic</td>
<td>0.9908</td>
<td>0.9859</td>
<td>0.9742</td>
<td>56.655</td>
</tr>
</tbody>
</table>


(2)
The significance of the model for BTE and BSFC as shown in the Table - 6 and Table - 7. The interaction graphs were obtained from the Design Expert software using the experimental data. They were generated for the injection pressure, the injection timing and the blend for the Brake Thermal Efficiency and Brake specific fuel consumption.

The contour plot and the surface plot for the brake thermal efficiency and brake specific fuel consumption are shown in Fig. 3 to Fig. 8. Figs. 3 to 8 show the variation between the injection pressure, the injection timing and the blend ratio. The predicted $R^2$ value for brake thermal efficiency and brake specific fuel consumption, 98.80 and 97.42 is very close to the Adjusted $R^2$ value, 99.40 and 98.59 as given in Table - 8. The p-value is less than 0.001. Hence the model is significant. It is observed from the Figs. 4, 6,& 8 showing the response surface plot of brake thermal efficiency and brake specific fuel consumption, that it increases from 180 bar to 240 bar, with injection timing being advanced from 21° BTDC to 27°BTDC and the blend from B10 to B40. The better performance of the DI diesel engine was observed at 240 bar, 27°BTDC and for B25. This could be due to the better spray characteristics and that would have effectuated better combustion.

**CONCLUSIONS**

The Mathematical model was developed using the response surface method to analyze the interaction among the injection pressure, the injection timing and the blend.

- In this study a quadratic model was developed and the value of $R^2$, 99.40 % and 99.08% is fitted exactly with the experimental data.
- The most significant values of the diesel engine were 240 bar, 27°BTDC and the blend B25.

**REFERENCES**


