Technical Note

Study on rapeseed oil as alternative fuel for a single-cylinder diesel engine

Y. He *, Y.D. Bao

College of Biosystem Engineering and Food Science, Zhejiang University, Hangzhou 310029, People’s Republic of China

Received 26 June 2002; accepted 12 October 2002

Abstract

This study was undertaken to provide knowledge necessary for raising the thermal efficiency of mixed oil composed of rapeseed oil and conventional diesel oil and for improving the performance of an engine fuelled by the mixture. The experimental results obtained showed that a mixing ratio of 30% rapeseed oil and 70% diesel oil was practically optimal in ensuring relatively high thermal efficiency of engine as well as homogeneity and stability of the oil mixture. Method of quadratic regressive orthogonal design test method was adopted in experiment designed to examine the dependence of specific fuel consumption on four adjustable working parameters when the above-mentioned oil mixture was used. These parameters were: intake-valve-closing angle (α), exhaust-valve-opening angle (β), fuel-delivering angle (θ) and injection pressure (P, in 10^4 Pa). Relationship between these parameters and specific fuel consumption was analyzed under two typical operating conditions and mathematical equations characterizing the relationship were formulated. The equation of specific fuel consumption derived from the regressive test under each operating condition was set as the objective function and the ranges for the four adjustable working parameters were the given constraint condition. Models of non-linear programming were then constructed. Computer aided optimization of the working parameters for 30:70 rapeseed oil/diesel oil mixed fuel was achieved. It was concluded that the predominant factor affecting the specific fuel consumption was fuel-delivering angle θ, the approximate optimal value of which, in this specific case, was 2–3 degrees in advance of that for engine fuelled by pure diesel oil. The experimental results also provided useful reference material for selection of the most preferable combination of working parameters.

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Keywords: Alternative fuel; Diesel engine; Rapeseed oil; Quadratic regressive orthogonal test design
1. Introduction

With the rapid development of rural agricultural production and rapid growth of village and town industry in China, disproportionateness between demand for and supply of energy has become an increasingly acute problem. Due to the seasonality of farm work, a temporary shortage of fuel will bring about an unexpected and irreparable loss to peasants. In areas where rape is a major crop and plenty of rape-seeds are harvested every year, it is possible to use rapeseed oil as an emergency auxiliary or endemic fuel of the diesel engine.

China is rich in rapeseed and research using rapeseed oil as diesel engine fuel has been intensively and widely studied here. From the technological point of view, the fuel property of rapeseed oil seems to meet the fundamental requirements of a diesel engine. Therefore, use of rapeseed oil blended with diesel oil as a substitute for conventional diesel oil in a diesel engine is reasonable and prospective. For such a proposal, modification of diesel engine structure is unnecessary as has been confirmed by literature [1–3]. However, there are certain differences between rapeseed oil and diesel oil, such as differences in spraying characteristics and combustibility [4], deserving our attention. It follows that the oil mixture will not ensure the most desirable status of combustion and, accordingly, sufficiently smooth engine performance, effective power utilization and economically adequate reward, unless relevant working parameters are readjusted in accordance with results of carefully designed experimentation [2–3].

2. Objective

The objective of this study is to procure the most desirable values for the relevant working parameters and their optimal combination based on the experiments with mixture fuel composed of rapeseed oil and conventional diesel oil.

3. Materials and methods

3.1. Experiment equipment

All engine tests were run on a S195 type single cylinder diesel engine, which is presently the main farm power machine in PRC, with technical specifications as shown in Table 1.

Both No.0 diesel oil and rapeseed oil purchased from the market were selected for performance test on the engine.
Table 1
The technical specifications of S195 type diesel engine

<table>
<thead>
<tr>
<th>Model</th>
<th>S195</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Lishui power plant, Zhejiang, PRC</td>
</tr>
<tr>
<td>Type</td>
<td>4-cycle, single cylinder, horizontal, water cooling</td>
</tr>
<tr>
<td>Type of chamber</td>
<td>Swirl chamber</td>
</tr>
<tr>
<td>Cylinder bore/stroke(mm/mm)</td>
<td>95/115</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>20:1</td>
</tr>
<tr>
<td>Rated power/rated speed(kW/rpm)</td>
<td>8.82/2000</td>
</tr>
<tr>
<td>Maximum power/speed(kW/rpm)</td>
<td>9.70/2000</td>
</tr>
<tr>
<td>Injection pressure(×10^4 Pa)</td>
<td>1226.25±49.05</td>
</tr>
<tr>
<td>Fuel-delivering angle (degree):</td>
<td>16–20 before top dead centre</td>
</tr>
<tr>
<td>Mode of start</td>
<td>Manual</td>
</tr>
</tbody>
</table>

3.2. Test methods

3.2.1. Evaluation index

The primary evaluation index for diesel engine burning blend composed of rapeseed oil and No.0 diesel oil is its thermal efficiency ($\eta_e$). The relationship between thermal efficiency $\eta_e$ and specific fuel consumption ($g_e$) is represented by:

$$g_e = \frac{3.6}{\eta_e H_u} \times 10^6$$  \hspace{1cm} (1)

where $H_u$ (low calorific value) is a constant which depends on the kind of the fuel. For convenience sake, we used the specific fuel consumption as an estimate of the thermal efficiency and, on account of the inverse relationship between them, a decrease in specific fuel consumption would reflect an increase in thermal efficiency. Thus, in the following tests, specific fuel consumption will be taken as the main evaluation index.

3.2.2. Quadratic regressive orthogonal test design

To reveal the relationship between adjustable working parameters of the engine and specific fuel consumption as well as to achieve optimal combination of the main influencing factors with these parameters, a quadratic regressive orthogonal test design involving four factors was conducted [5]. The experiment was performed with a blend composed of 30% rapeseed oil and 70% diesel oil under two typical operating conditions.

The experiment was designed to find out the most influential factor which would affect thermal efficiency of the engine through the help of performing a quadratic regressive orthogonal test. Two typical operating conditions under which the experiment was carried out were: (1) 7.35kW/2000 rpm and (2) 8.82kW/2000 rpm.

Four working parameters relevant in the experiment and represented by $X_1$, $X_2$, $X_3$, and $X_4$ were intake-valve-closing angle ($\alpha$), exhaust-valve-opening angle ($\beta$), fuel-
Table 2
Design Level of Four Variables in the quadratic regressive orthogonal test concerning the effect of working parameters on thermal efficiency

<table>
<thead>
<tr>
<th>Variable</th>
<th>Changing Interval</th>
<th>Design Level of Variables(m, r=2, r=1.483)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td>−r</td>
</tr>
<tr>
<td>(X_1)</td>
<td>6.743</td>
<td>33</td>
</tr>
<tr>
<td>(X_2)</td>
<td>6.743</td>
<td>33</td>
</tr>
<tr>
<td>(X_3)</td>
<td>2.697</td>
<td>14</td>
</tr>
<tr>
<td>(X_4)</td>
<td>132.3</td>
<td>1030.1</td>
</tr>
</tbody>
</table>

delivering angle (\(\theta\)) and injection pressure (\(P_i\) in \(10^4P_a\)) respectively. The arrangement of these parameters and the levels of variables chosen are shown in Table 2.

4. Experimental results and analysis

4.1. Relationship between different mixing ratio of the constituent oils and specific fuel consumption

When pure rapeseed oil is used as fuel, the high viscosity of the liquid constitutes a serious difficulty to study and results in a serious carbon deposit within the engine. To reduce viscosity, an oil mixture was used instead. Experiments were performed to examine the effect of the mixing ratio of rapeseed oil and diesel oil on combustion efficiency. The result shown in Table 3 points to relatively high specific fuel consumption of the mixture fuel as compared to pure No.0 diesel oil. Specific fuel consumption increased with the increase in proportion of rapeseed oil in the mixture. 20-30% rapeseed oil in the mixture led to a 3–5% increase in specific fuel consumption and significantly a much more rapid increase in fuel consumption occurred with the further addition of rapeseed oil. Experiments under two distinct operating con-

Table 3
Relationship between rapeseed oil to diesel oil mixing ratio and specific fuel consumption under two typical operating conditions of the engine

<table>
<thead>
<tr>
<th>Rapeseed oil / diesel oil</th>
<th>Specific fuel consumption (g_c) (g/kW.h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.35kW/2000 rpm</td>
</tr>
<tr>
<td>0/100</td>
<td>266.67</td>
</tr>
<tr>
<td>10/90</td>
<td>274.29</td>
</tr>
<tr>
<td>20/80</td>
<td>276.60</td>
</tr>
<tr>
<td>30/70</td>
<td>280.14</td>
</tr>
<tr>
<td>50/50</td>
<td>296.87</td>
</tr>
<tr>
<td>70/30</td>
<td>304.35</td>
</tr>
</tbody>
</table>
conditions gave the same result. Provided the rapeseed oil content did not exceed 30%, the homogeneity of the mixture could be maintained for as long as a whole year under ordinary temperature conditions. When the rapeseed oil content was increased to 40%, sediment would appear in 1–2 weeks. Raising the rapeseed oil content to 50% caused sedimentation within one week. Accordingly, rapeseed oil to diesel oil ratio of 30–70 was considered most preferable.

4.2. Result of quadratic regressive orthogonal test

After significance test on regression coefficients and regression formulas, the equations that relate the four working parameters to specific fuel consumption for the two operating conditions were formulated as follows.

Operating Condition (1):

\[
g_{e1} = 1131.129 - 10.871\alpha - 0.415\beta - 60.653\theta - 0.021P + 0.136\alpha\theta + 8.044 \times 10^{-4}\theta P + 0.101\alpha^2 + 1.407\theta^2
\]
Operating Condition (2):

\[ g_{e2} = 1017.271 + 0.216\alpha - 12.415\beta - 39.893\theta - 3.772 \times 10^{-2}P \]
\[-0.0599\theta\beta + 0.151\beta^2 + 1.094\theta^2 \]  

Based on variable analysis and the above regression equations, fuel-delivering angle \( \theta \) was found to be the most important factor among the four working parameters that had influence on specific fuel consumption.

4.3. Optimization of working parameters

In our analysis, the regression equations for the two operating conditions were taken as the objective functions, and the test ranges of working parameters the constraint conditions. Therefore, the nonlinear programming mathematics models would be:

4.3.1. Operating condition (1)
4.3.1.1. Objective function  
\[ g_{e1} = 1131.129 - 10.871\alpha - 0.415\beta - 60.653\theta - 0.021P + 0.136\alpha\theta + 8.044 \times 10^{-4}\theta P + 0.101\alpha^2 + 1.407\theta^2 \]  

4.3.1.2. Constraint condition  
\[ 33 \leq \alpha \leq 53, \quad 33 \leq \beta \leq 53, \quad 14 \leq \theta \leq 22, \quad 1030.1 \leq P \leq 1422.5 \]

4.3.2. Operating condition (2)
4.3.2.1. Objective function  
\[ g_{e2} = 1017.271 + 0.216\alpha - 12.415\beta - 39.893\theta - 3.772 \times 10^{-2}P - 0.0599\theta\beta + 0.151\beta^2 + 1.094\theta^2 \]  

4.3.2.2. Constraint condition  
\[ 33 \leq \alpha \leq 53, \quad 33 \leq \beta \leq 53, \quad 14 \leq \theta \leq 22, \quad 1030.1 \leq P \leq 1422.5 \]

With the help of computer, the optimal combinations of the four working parameters under the two operating conditions were determined by applying the method of composite punishment function to resolve the two nonlinear programming [1]. The following results were obtained: Operating Condition (1): \( \alpha = 40.7^\circ, \beta = 53^\circ, \theta = 19.1^\circ, P = 14.22 \text{ MPa}, g_e = 288.65 \text{ g/kW.h.} \) Operating Condition (2): \( \alpha = 33^\circ, \beta = 41^\circ, \theta = 20^\circ, P = 14.22 \text{ MPa}, g_e = 303.82 \text{ g/kW.h.} \)

4.3.3. Theoretical analysis of change in desirable values for working parameters

According to the results of the test, fuel-delivering angle \( \theta \) was the adjustable parameter that exerted a predominant influence on fuel consumption. If \( \theta \) was too big, fuel oil would be injected into the cylinder under low pressure and gas temperature, so that the physical and chemical prerequisites were not sufficiently fulfilled. Such a condition was inappropriate for adequate gas mixing and would lead to prolonged ignition delay. As a consequence, the rate of cylinder pressure rise (\( \Delta P/\Delta \phi \)) was enhanced and thus resulted in rude operation of engine. On the other hand, too small a \( \theta \) tended to incur the extension of burning time, which then would be com-
pleted only after the piston had struck the top dead center. In this case, the attainable maximal peak cylinder pressure would be comparatively low, the exhaust temperature comparatively high, and the thermal efficiency appreciably reduced.

On the basis of our experiment on an S195 diesel engine fuelled by mixed rapeseed oil/diesel oil in ratio of 30:70, we tried to approach the problem of relationship between fuel-delivering angle and fuel consumption rate. According to the data obtained, the optimal fuel-delivering angle was 20–21 degrees, i.e. advanced by 2–3 degrees compared to that for unblended diesel oil. This was due to the fact that rapeseed oil has a lower cetane number, higher viscosity, inferior ignition quality and, hence, longer combustion duration than pure diesel oil. So we expect that moderately larger fuel-delivering angles should be favorable for improving engine performance.

5. Conclusion

Rapeseed oil is promising as an alternative fuel source for the diesel engine because of its high gross heat content. It can be directly used as a diesel fuel and does not need any change in the structure of the engine. However, in order to attain the highest power and thermal efficiency, relevant working parameters of the engine should be readjusted. In the present study, optimal combinations of four working parameters under two operating conditions were determined when the mixture of 30% rapeseed oil and 70% diesel oil were used in an S195 diesel engine.

Based on quadratic regressive orthogonal tests of four working parameters, the main factor influencing the specific fuel consumption or thermal efficiency was found to be the fuel-delivering angle, and its optimum values for two operating conditions in our experiment were about 20 degrees, that is 2–3 degrees in advance of that which was appropriate for the engine fuelled by pure diesel oil.

The high viscosity of rapeseed oil is one of the key problems preventing its wide application. Test results reported in this paper showed that the mixture of 30% rapeseed oil and 70% No.0 diesel oil was suitable for it to be used as diesel fuel.

References